HYDRODYNAMIC STABILITY OF TENSION LEG PLATFORM (TLP)

MOHD HAFIZ BIN NAIB MUDDIN

CIVIL ENGINEERING
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FINAL YEAR PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

January 2009

CERTIFICATION OF APPROVAL

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Approved by:

Associate Professor Dr. Saied Saiedi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Hafiz bin Naib Muddin

ABSTRACT

This report basically describes the hydrodynamic stability of Tension Leg Platform (TLP) due to wave and current. First part of this report, it gives information on Background Studies and the objective of the research. Literature Review is the second part of this report and it describes on types of TLP, buoyancy and stability of TLP, the scale modeling of a prototype.

Third part is Methodology where it explains the steps of the research. Every step is essential in this research. It mainly describe about how the experiment are going to be conducted and what parameter involves in the test. There is also a diagram showing the work flow of the research. In this part it describes most of the work or activities that was done.

On the Result and Discussion section, experimental result was taken from laboratory was analyzed in the model response to wave and current. Last but not least, Conclusion of this report will be concentrate on TLP movement (surge and sway).

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Mohd Hafiz bin Naib Muddin

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INTRODUCTION

1.1 Background of Study

As time goes on, science and technology is getting forward. 40 years back, a concrete structure is too thick, but nowadays, it has become thinner as engineers and scientist are getting closer and prefer to optimize concrete structure. The same goes for Tension Leg Platform (TLP). Analysis of hydrodynamic stability of TLP will give a clearer idea on what is the force acting on the platform, which way is the force, what type of forces that needed to be considered and forces that can be neglected. From this analysis, a more optimized platform design will produced by engineer. As for this research, it will mainly discuss about movement of TLP. The expected movements of TLP are surge and sway.

For recent and future needs of offshore structure, TLP has very bright future. TLP is different with Fixed Platform structure such a jacket platform and gravity based structures that were famously used previously. Nowadays as most of the near shore oil was discovered, oil exploration begins in deep water. TLP is very suitable for this depth. TLP is vertically moored at each corner of hull to minimize the movement of the structure.

Basically there are two major types of model which are display model and engineering model. These two differs from each other by its purpose. For research project, most of the time engineering model is used to collect any significant and useful data in the design of the structure. From model testing, the behavior of the actual structure can be predicted.

1.2 Problem Statement

Oil and gas industry can be considered as a huge industry around the world. This industry kept on evolving and has been increasing each decade. Previously, the pre-dominant location of oil exploration for petroleum and gasses are located at Gulf of Mexico and North Sea. Nowadays, other sea region has produced quite a large volume of petroleum.

Basically, the number one factor which had the major influence in the design of offshore structure is water depth. As water depth increases, the cost of constructing an offshore platform will also increase. Two major types of platform were introduced which are Compliant Platform and Floating Platform to reduce or minimize the constructing cost for deepwater offshore structure. TLP is one of those two types of platform which will be widely used in this few decades.

1.3 Objective and Scope of Study

The main objective of this project is to verify or compare the guides and formulas in the literature on the hydrodynamic stability of a TLP.

Scope of study:

i. To identify a real-life tension leg platform and to collect the relevant hydrodynamic stability data.

ii. To build the scale model of the platform

iii. To conduct test on the wave and possibly current.

iv. To compare the results with the formulas and guide available.

1.3.1 Relevancy of the Project

There are hundreds of oil platforms nowadays. An analysis of a designed offshore platform is essential as it gives us information on how it reacts due to some forces. This analysis helps designer to identify whether there will be problems on the designed structure.

1.3.2 Feasibility of the Project

Since this project requires the author to conduct a few tests, a model is needed. Since it is just a scale model, the model will be somehow constructed in a big scale which resulted into a smaller scale model to be constructed. A small model is workable and it can be constructed. But a small structure should not compromise the scale and it should represent the actual structure. In terms of cost, with the right material, and thickness it will not cost as much as RM 300.00 to build the model.

CHAPTER 2
LITERATURE REVIEW AND/OR THEORY

2.1 TYPE OF PLATFORM

The exploration of oil and gas was started back in the nineteenth century. During that time, the first few oil and gas exploration were located in Gulf of Mexico and North Sea. These two locations are the previous heaven for oil and gas industry. The main activity of this industry located at sea, also known as offshore works. In order to do exploration work at sea, an offshore platform was introduce and as time goes on, few other types of offshore platform developed. This is due to the sea condition at the site which primarily due to its water depth. Overall there are three types of offshore platform which are:

- Fixed Platform – suitable for shallow water
  - Jacket Platform
  - Gravity Base Structure (GBS)
- Floating Platform – suitable for deep water operation
  - Semi Submersible
  - Spar Platform
- Compliant Platform – suitable for deep water operation
  - Guyed Tower
  - Articulate Tower
  - **Tension Leg Platform (TLP)**

There are many criteria in choosing which type of platform is suitable. But two factors that cannot be separated in making the decision are cost and water depth at oil deposits.

Tension Leg Platform (TLP)

Tension Leg Platform (TLP) is in Compliant Platform and it is a buoyant platform which is held by mooring system. The mooring is also known as tether. TLP is different from fixed platform because the overall or main structure does not touches seabed. It floats at sea and tethered to sea by the mooring system. Mooring system plays a big role in TLP as its primary purpose is to hold the platform so that it would not have any significant movement. Mooring line is also a set of tension tethers which are attached to the corner of platform and connected to the sea floor.

Initially the TLP concept was generated from Conoco Oil Company. They came up with an alternative to fix the steel structure and Floating Production System (FPS). This alternative is for them to develop water oil and gas field. The first TLP was built in 1984. It used to develop the Hutton field which is located in North Sea, but now it is no longer in service. Water depth for this TLP is approximately to be 148m and it is the shallowest TLP ever built. On the other hand, the deepest TLP is known as Conoco Magnolia TLP. Up until at this moment, there are 19 TLP exists around the world.

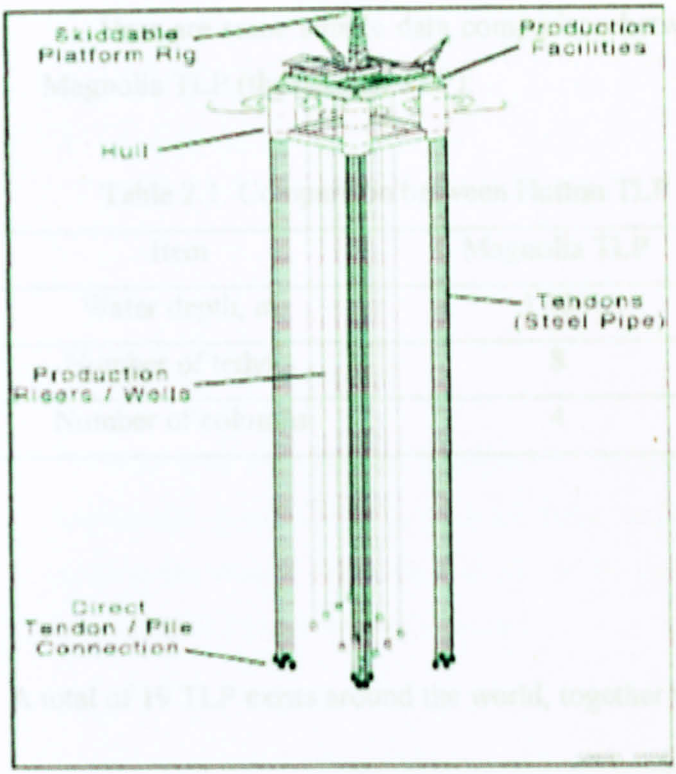

Figure 2.1: A conventional TLP

From Figure 2.1, it shows the main parts of conventional TLP. It has topside, column, pontoon, tether (tendon), hull, riser and template. Hull is a buoyant structure where topside sits on top of it. Hull also supports the oil production facilities and accommodation for workers. The pontoon and columns were designed to provide buoyancy to maintain the deck above the wave in all condition. Tether is a mooring which connects and hold hull from moving vigorously. Template provides frame on the sea floor, where it is the place to insert either conductor or pile.

There is another type of TLP which is SeaStar TLP. A mini TLP is called as SeaStar. This mini TLP is combining together the concept of SPAR platform and favorable response features of a TLP. This SeaStar TLP perform its function as an independent production platform on fields which containing smaller petroleum reserve. It can also acts as an early production platform, for a large deepwater oil discovery (oil deposit). Until now, the SeaStar TLP has not been fully developed. Oil and gas companies see the SeaStar future as bright and starting to develop to unlock the economic potential. Right now, there are many SeaStar TLP operated all around the world. Such SeaStar TLP are; ENI Allegheny, ENI Morpeth and Chevron/Texaco Typhoon.

Here are some simple data comparison between Hutton TLP (first TLP) and Magnolia TLP (the deepest TLP):

Table 2.1: Comparison between Hutton TLP and Magnolia TLP

Item	Magnolia TLP	Hutton TLP
Water depth, m	1 424	148
Number of tethers	8	16
Number of columns	4	6

A total of 19 TLP exists around the world, together with its water depth:

Table 2.2: All TLP constructed with respect to its birth year and water depth.

Name of TLP	Water Depth (m)	Year
KM Hutton	148	1984
Conoco Jolliet	536	1989
Snorre	335	1992
Auger	872	1994
Heidrun	351	1995
Mars	896	1996
Ram-Powell	980	1997
ENI Morpeth	518	1998
Ursa	1200	1999
Marlin	988	1999
ENI Alleghney	1000	2001
El Paso Prince	457	2001
Chevron/Texaco Typhoon	671	2001
Brutus	910	2001
Matterhorn	945	2003
Unocal West Seno 1	1021	2003

Kizomba	1177	2003
El Paso Marco Polo	1311	2003
Conoco Magnolia	1432	2003

2.2 Buoyancy and Stability

Buoyancy phenomenon is caused by the dispersing of fluid by a body. From Archimedes principle: "The buoyant force acting on a body immerse in fluid is equal to the weight of the fluid displaced by the body, and it acts upward through the centroid of the displaced volume".

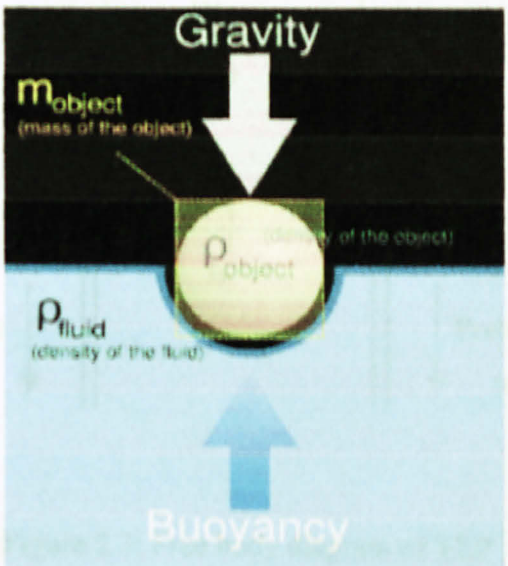

Figure 2.2: Buoyancy theory

Buoyancy is the upward force on an object produced by the surrounding liquid or gas in which it is fully or partially immersed, due to the pressure difference of the fluid between the top and bottom of the object. The net upward buoyancy force is equal to the magnitude of the weight of fluid displaced by the body. This force enables the object to float or at least to seem lighter. For a solid uniform density, its weight also acts through the centroid, but its magnitude is not necessarily equal to the fluid it displaced. Hence this solid body will sink.

Pressure increases with height above the surface of a liquid. As the object goes down into water, the pressure is also increase. Any object with a non-zero vertical height will have different pressures on its top and bottom surface. Normally, the pressure on the bottom being greater compared to top water surface. The reason for the existence of buoyancy is causes the upward buoyancy force.

For TLP, buoyancy (B) is equal to the weight (w) of TLP added with the pre-tension (p) of tethers.

Buoyancy (B) = Weight (W) + Pre-Tension (T).

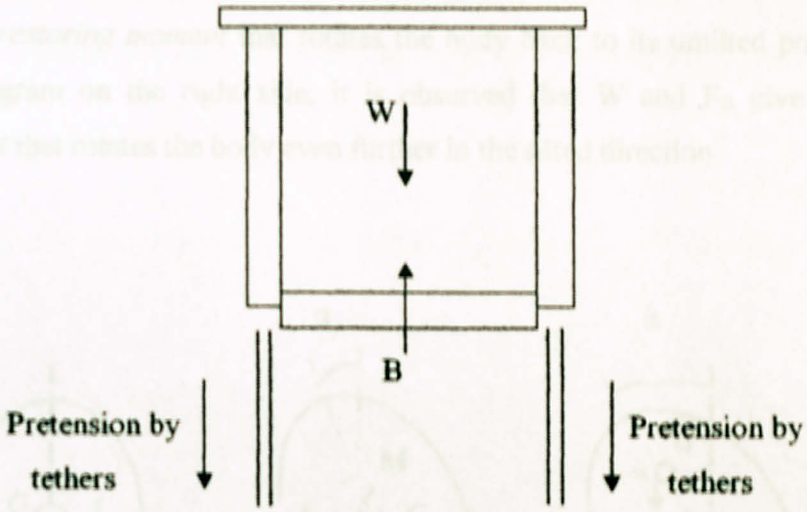

Figure 2.3: Free body diagram of TLP

Stability of Floating Bodies

Stability is an important characteristic to be considered in this project. It is necessary for TLP to have a good stability as it floats at sea. Sea current, wave and wind contains energy which will then translate to force and pressure and hit TLP which will affect its stability. As we all know, TLP is a floating type of platform. If the bottom part of TLP is heavy, (center of gravity, G is higher than buoyancy,

B) then TLP will be stable. Floating bodies can be stable when G is higher than B due to shift location of center buoyancy and creation of restoring moment.

A floating body is stable if, when it displaced, it returns to equilibrium and unstable if when it displaced, it moves away to a new equilibrium. Consider a floating body tilted by an angle α, for the untilted body the point G is where the body weight, W acts. At point B, buoyancy force acts upward. When the body tilted to the center of buoyancy moves to a new position, B' because the shape and displaced volume changes. A new point, M, called Metacentre. This is the pint where a vertical line drawn upwards from the new centre of buoyancy, B', of the tilted body intersects the line of symmetry of the body. The buoyancy force, F_B now acts through B'. From the centre diagram below, we can see that W and F_B give a *restoring moment* that rotates the body back to its untilted position. From the diagram on the right side, it is observed that W and F_B give *overturning moment* that rotates the body even further in the tilted direction.

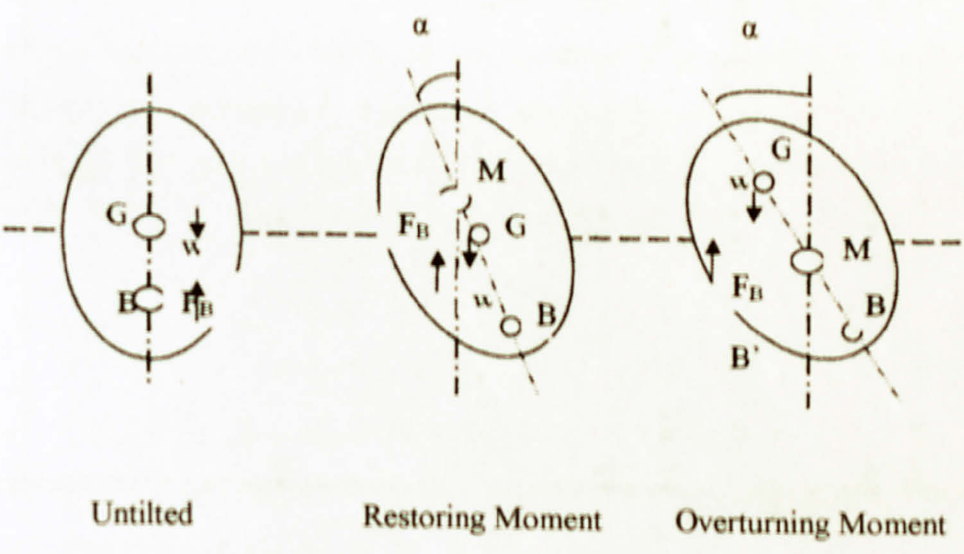

Figure 2.4: Stability of a particle in water

2.3 Laboratory Testing

Laboratory testing will be conducted after the modeling of TLP is complete. The primary purpose of laboratory testing is to see the displacement of TLP scale model in wave tank. Forces (tension) on tethers will also be determined in the laboratory.

Wave tank is a laboratory setup or equipment for observing the behavior of waves. The typical wave tank around the world is a deep, transparent-sided box filled with liquid, generally water, leaving open or air-filled space on top of it. At one end of the tank, there is an actuator which formed by a series of paddle. The function of an actuator is to generate waves in the wave tank. At the other end of tank, it has a wave-absorbing surface. A similar device is the ripple tank, which is flat and shallow and used for observing patterns of surface waves from above.

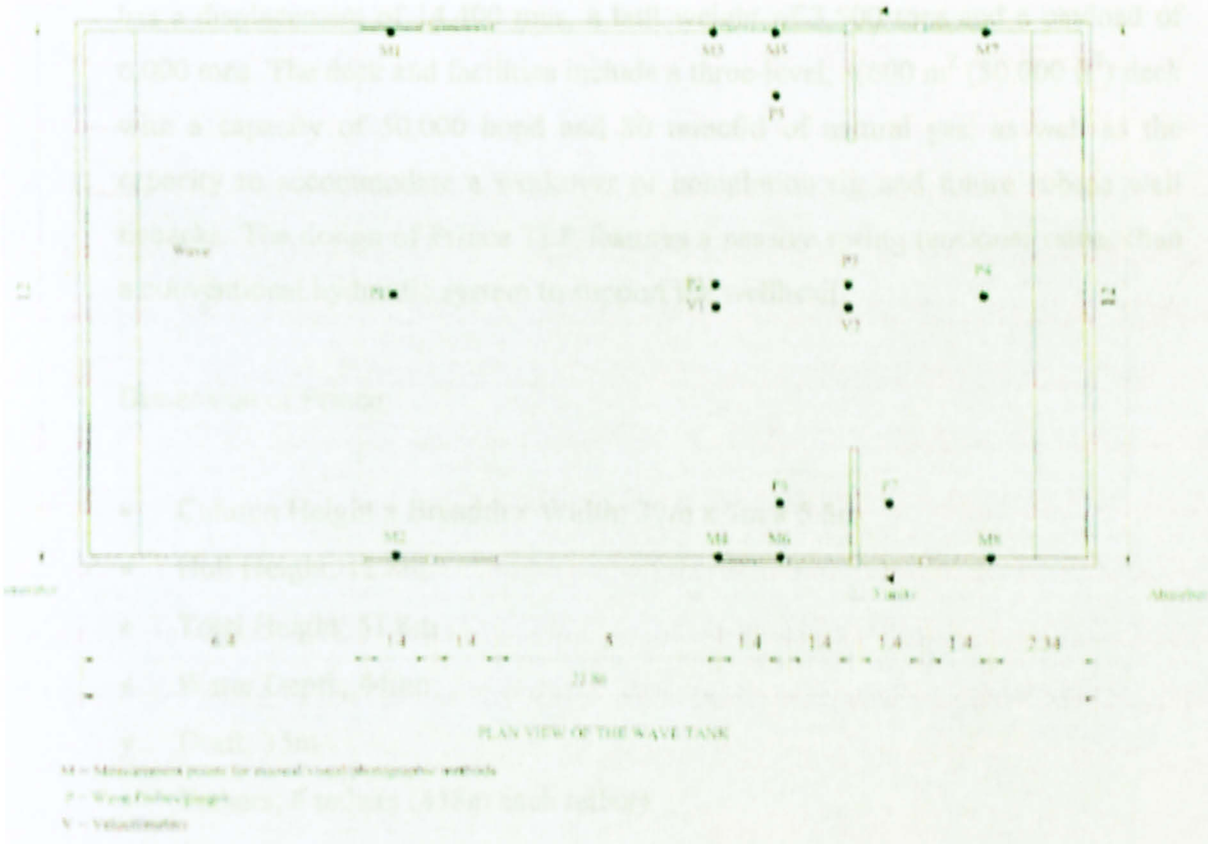

Figure 2.5: Plan View of the Wave Tank

2.4 Real Life Tension Leg Platform Project

A Tension Leg Platform (TLP) is one of three types of compliant tower used for the offshore production of oil or gas. Compliant towers are designed to sustain significant lateral deflections and forces, and are typically used in water depths ranging from 1,500 and 3,000 feet (450 and 900 m). TLP is an oil platform which is tethered by special steel lines attached to seabed. This allows TLP to have surge and sway movements. But there is a limit to these movements.

The name of this tension leg platform is "Prince" which is owned by "El Paso". It is located at Gulf of Mexico, United States of America (USA). The exact location is in Gulf of Mexico Block EB 1003, approximately to be 190 km off the south of New Orleans coast. This is the world's first mini TLP constructed to support producing wellheads. The platform will process production from future oil and gas developments in the Ewing Bank and Green Canyon. The Prince platform includes the first mini-TLP hull constructed to support producing wellheads, and has a displacement of 14,400 tons, a hull weight of 3,500 tons and a payload of 6,000 tons. The deck and facilities include a three-level, 4,600 m^2 (50,000 ft^2) deck with a capacity of 50,000 bopd and 80 mmcf/d of natural gas, as well as the capacity to accommodate a workover or completion rig and future subsea well tiebacks. The design of Prince TLP features a passive spring tensioner rather than a conventional hydraulic system to support the wellhead.

Dimension of Prince:

- Column Height x Breadth x Width; 39m x 7m x 5.5m
- Hull Height; 12.8m
- Total Height; 51.8m
- Water Depth; 440m
- Draft; 35m
- Tethers; 8 tethers (438m each tether)

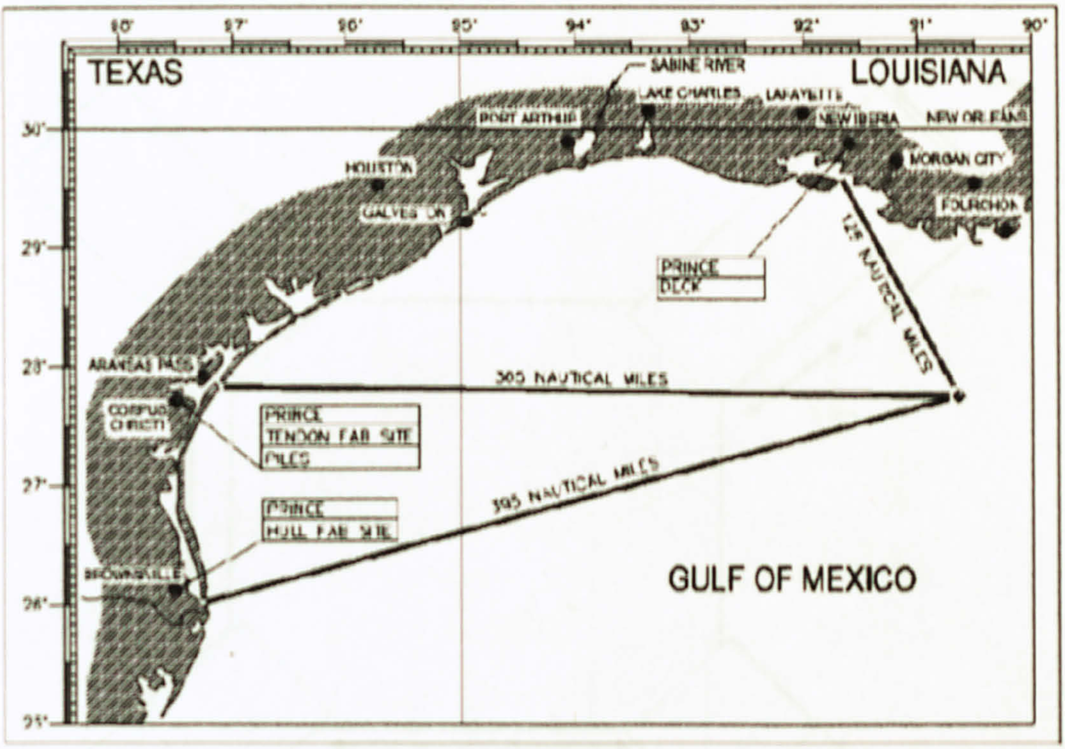

Figure 2.6: Location Map of El Paso Prince Platform

Figure 2.7: Topside View of Prince Platform

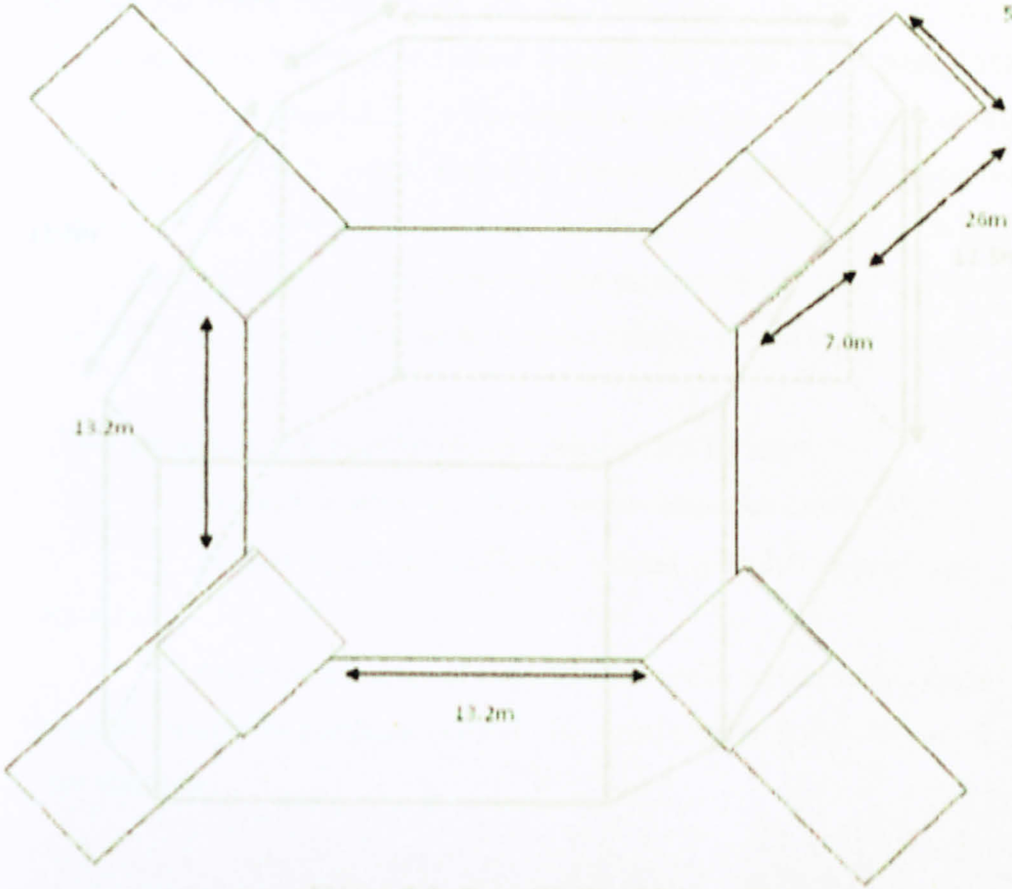

Figure 2.8 : Plan view of Prince TLP

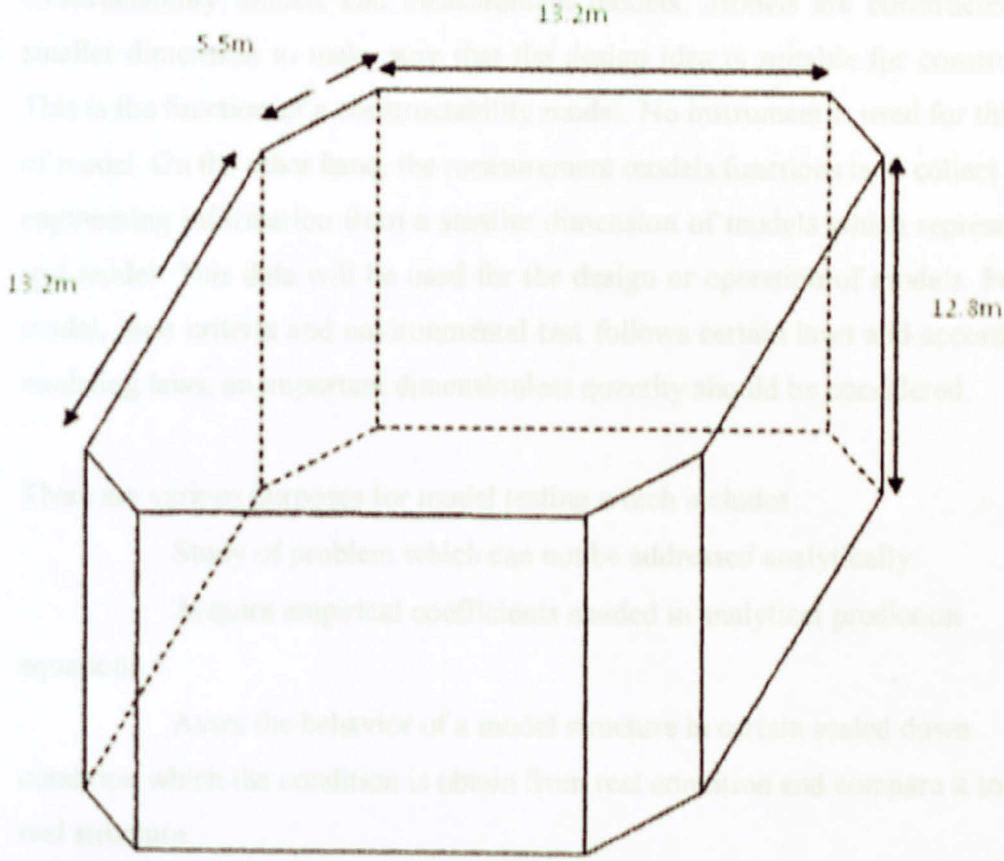

Figure 2.9: Base (Hull) of Prince TLP

2.5 Modeling

In every part of the world, humans learn from models. The same thing goes for engineer, which continuously working with models. Despite how it looks, what type of model it is, and/or the construction model, every model has an essential value and stand for the actual information. All of these models permit us to verify a whole new idea and also proves a design.

Display models which used to describe one concept and engineering models which its primary purpose to gather valuable data for item under consideration; are the two major types of models.

For engineering models, it can be divided further to two groups: constructability models and measurement models. Models are constructed to a smaller dimension to make sure that the design idea is suitable for construction. This is the function of a constructability model. No instrument is used for this type of model. On the other hand, the measurement models functions is to collect useful engineering information from a smaller dimension of models which represent the real model. This data will be used for the design or operation of models. For this model, their criteria and environmental test follows certain laws and according to modeling laws, an important dimensionless quantity should be considered.

There are various purposes for model testing which includes:

- Study of problem which can not be addressed analytically.
- Acquire empirical coefficients needed in analytical prediction equations.
- Asses the behavior of a model structure in certain scaled down condition which the condition is obtain from real condition and compare it to the real structure.

It can be concluded that model testing is an experimental practice used to verify actual theory, calculation and analysis at the first place.

Modeling is a process of constructing a structure (model) with relatively high scale. Modeling is done by scaling down the original structure, the choices of material used for modeling, and the construction of model itself. Before modeling is done, a complete information of a tension leg platform (TLP) in the world should be obtained. From this data, we can do calculation to obtain the exact dimension for the scaled model. The scale can be refer to "Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994)"

After calculating the scale factor in which the model to be constructed, material for construction is to be considered. For modeling of a real structure, it is preferably not to change the original material from original structure. Different material will react in different ways. A change in material usage can result in different problem arises as it has different behaviour. Example of scale calculation by referring to Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994)":

CHAPTER 3
METHODOLOGY

3.1 Work Diagram

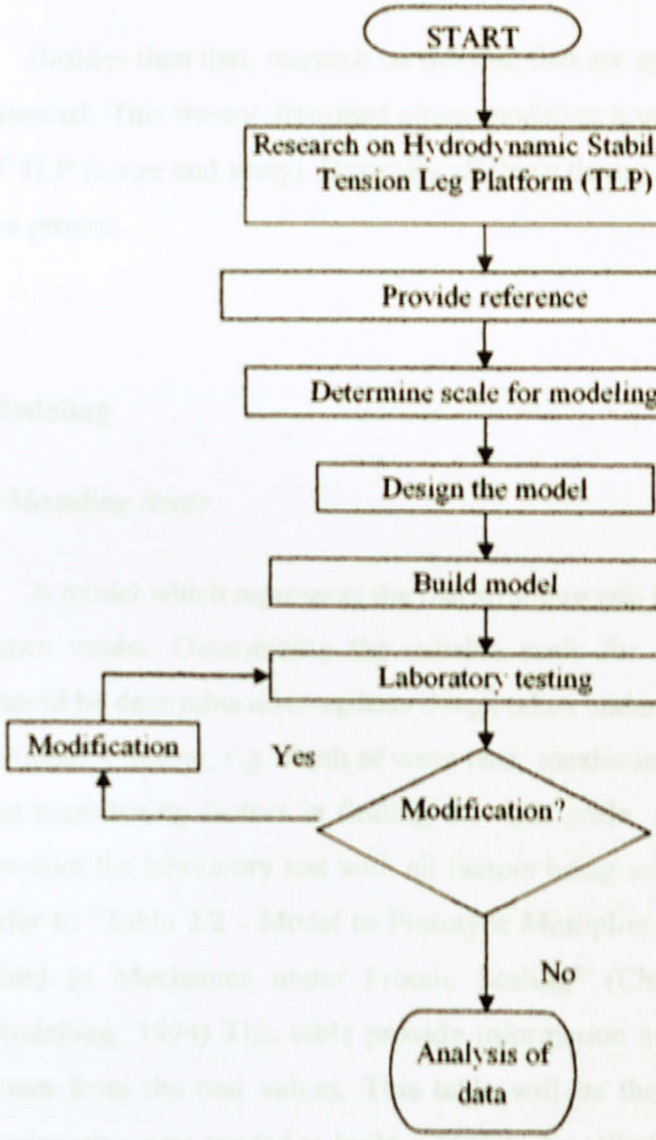

Figure 3.1: Work Diagram for FYP

3.2 Research

In this category, research is done continuously to gain extra information. All useful information that related to the project can be obtained from journals, articles, books, magazine and websites (general information only). Online journals can be obtained from *"ScienceDirect, ASCE Online Journals, Scholar_Google"* websites. Besides online journal, the Information Resource Center (IRC) offers a wide collection of journal and also books. The purpose of this activity is to find the literature review, research paper on topics that are related to hydrodynamic stability of TLP.

Besides than that, research on theories that are applicable to the project is also essential. This theory discussed about modeling a prototype, stability, movement of TLP (surge and sway). Basically all these theory is very helpful in completing the project.

3.3 Modeling

3.3.1 Modeling Scale

A model which represents the real structure will be constructed in a scaled down model. Determining the suitable scale for modeling is essential and it should be determine after various things taken under consideration. Limitation for laboratory testing, e.g. depth of wave tank, maximum wave velocity produced, are the contributing factors in finding the right scale. A suitable scale allows us to conduct the laboratory test with all factors being scaled down. The scale can be refer to "Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994) This table provide information and formulas on how to scale down from the real values. This table will be the main reference to calculate engineering data needed to build a Tension Leg Platform (TLP).

Calculation Example:

Parameter	Actual	Scale model	Scale Factor*
Water Depth	440 m	?	α
Weight	9649.89 ton	?	$200^3=\alpha^3$

**These scale factor can be obtained from "Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994).*

Calculation in determining the scale, α

Let say we want the scale model to have water depth of 1m;

α = scale;

$$\frac{1}{\alpha} \times \text{actual parameter} = \text{scale model parameter} \quad \text{.................................(3.1)}$$

$$\frac{1}{\alpha} \times 440\ m = 1\ m$$

$$\alpha = 440$$

So, the scale that we need for model to have 1m water depth which represents 440m is 1:440.

But the real project does not use scale of 1:440 due to the limitation of water tank depth. As a result, water depth is the only parameter which is not according to scale.

Equation 3.1 can be use to calculate data for the actual and scale model parameter, and also the scale. But the scale factor should be correct as in the table.

Second parameter: Weight;

Now, let us use the scale of 200 to calculate the scale model weight

$$\frac{1}{\alpha^3} \times \textit{actual weight} = \textit{scale model weight}$$

$$\textit{Scale model weight} = \textit{actual weight} \times \frac{1}{\alpha^3}$$

$$= 9649.89 \times 10^3 \times \frac{1}{200^3}$$

$$= 1.21\ kg$$

Third parameter: Draft;

A scale of 200 was chosen and the scale factor is α

$$\frac{1}{\alpha} \times \textit{actual draft} = \textit{scale model draft}$$

$$\textit{Scale model draft} = \textit{actual draft} \times \frac{1}{\alpha}$$

$$= 35m \times \frac{1}{200}$$

$$= 0.18m$$

The two most important factors in designing the scale model are draft, and the weight. Weight plays a big role as it will affect the buoyancy of the structure itself. It gives an idea how deep the structure is going to partially submerge in the water tank. On the other hand, draft is also important as it is the draft for the real life TLP. The analysis can only be done when the scale model is complying to the draft.

3.3.2 Material for Modeling

In designing the model, scale factor should be taken into consideration as we tried to build a model which will represent the real structure. Besides the scale, material which is to be use for model construction should also be considered. It is better not to change the material from the material of real structure. If material is not the same, it is feared that these materials has different properties, behaviour and reaction in water. But material change is allowable if the usage similar material to actual structure is impossible due to cost or feasibility.

In designing the model, the author is currently considering a material which is the most suitable to build the TLP. Thickness, density and weight of the material is crucial to achieve as the weight gives the indication whether this TLP model structure has a less weight compare to its buoyancy. It really matters because it will not sink if the weight is less than buoyancy. But, in the process, Perspex is the best material choice due to its hardness, visibility and it floats in water. Density of perspex is 1190 kg/m^3 is more or less the same with the fresh water density. This means that perspex can float in water. The floatation of prespex in water is in the much help of buoyancy force which push it up to the surface. That is the reason why it can float in water. In terms of visibility, it s almost clear as a glass and it gives a good look to the prototype.

With perspex, anybody can see the other end of the model clearly. Not only the visibility and density of perspex were taken under consideration, the hardness and its breaking strength is high which makes it ideal for modeling purpose in a wave tank. The wave and/or current generated from wave tank could be vigorous to do damage to the model. So, by looking at its hardness, it is a hard material. The breaking strength of perspex is much higher compared to glass. This can be prove by dropping a glass and a perspex with the same volume from a standard free fall of 1m. The glass will break and shatter but perspex will not shutter, let alone breaks. That is the description on how tough perspex is.

After choosing the right material (perspex), the designing process takes place. Designing involves drawing a scale model of Prince TLP. Every dimension of Prince TLP such as column height, column width, column breadth, dimension of hull and the dimension of tendon support structure were drawn according to the scale of 200. The purpose of the drawing is to see or give an overview on how big the scale model is. Overview on overall size of the model is important. It allows us to see or imagine how big or small it is and think about the workability. By workability here means, the easiness to lift it, easy to bring anywhere, total weight that can still be lift, and not to forget the installation or model setting up in the wave tank later on. Besides that, it also acts a reference to contractor who fabricates the model.

3.3.3 Construct Model

After the process of selecting the material for modeling is approved by FYP Supervisor, construction of TLP takes place. During this time, the scale of model has been verify, and all materials which will be use for construction is also finalize. The construction takes place by referring to the scale and using material that have been approved. Purpose of this model constructing is to prepare a model which can be use for analysis of a TLP which refers to the El Paso Prince TLP structure at Baldpate, Gulf of Mexico.

The model design (drawing) which was prepared in the "*3.2.3 Design the Model*" part is the reference to build the model. Due to the complicated of the design itself, which means it cannot be built personally, contractor who specialize in shaping, cutting and assembly material from perspex is the best option. By referring to the design, negotiation was done with the contractor to see whether they understand on what is the shape of the model. Another question that needs to be solved is whether they can fabricate the model according to the design. Due to the environment of the structure later on will be in a wave tank, the model should be water resistance. By water resistance, it means that at no point of the model, water from environment can leak inside to the structure. Leakage will result in the addition of water (weight) inside the model. This phenomenon will affect the behavior of structure laboratory test later on.

3.4 Pre Tension in Tethers:

Pre Tension in tethers is the force needed to hold the TLP at its draft.

Pre Tension in Tethers (P) = Buoyancy (B) – Weight of Model (W)……………(3.1)

Known parameters;
Weight = 1.2 kg or 11.77 N
Sea water density = 1030 kg/m^3;
Gravity = 9.807 m/s^2

Buoyancy (B) = Hull Buoyancy (B_H) + Column Buoyancy (B_C) + Tendon Support Structure Buoyancy (B_T)……………(3.2)

Buoyancy of Columns (B_C)

No of columns x height x breadth x width x sea water density x gravity……………(3.3)

Buoyancy of hull (B_H)

Volume of hull x sea water density x gravity……………(3.4)

Buoyancy of Tendon Support Structure (B_T)

4 x volume of tendon support structure x sea water density x gravity……………(3.5)

By substituting equation 3.2 into 3.1;

Pre Tension in Tethers (P) = (B_C + B_H + B_T) – (W)……………(3.6)

Tension in each tether (T) = P / No of tethers……………(3.7)

3.5 Hydrostatic Stability

Three main components that are crucial in determining the stability of floating structure are Metacenter (C_M), Center of Gravity (C_G) and Center of Buoyancy (C_B). For this model, all these points are located at the center of the model (origin at x and z axis). Due to the symmetrical shape of the model, the structure was divided into 4 parts to determine (C_G) and (C_B).

To determine the stability of the model these are the steps

1. Find the location of Center of Gravity, (C_G) (in y-axis)

The model were constructed using perspex with 0.004m thickness; density of perspex is 1190 kg/m^3

Position of center of gravity located in the center of perspex plate for rectangular shape.

$$\text{Center of Gravity } (C_G) = \frac{Y1W1 + Y2W2 + Y3W3 + \ldots + YnWn}{W1 + W2 + W3 + \ldots + Wn} \qquad (3.8)$$

Y = position of center of gravity for each perspex plate. (from bottom of the model)
W = weight of each perspex plate

Weight of each perspex plate = area of perspex plate x thickness x density of perspex. Since the model is divided into 4 parts, the weight can be taken as ¼ to the model weight which equals to 0.3075kg.

2. Find the location of Center of Buoyancy (C_B) (in y-axis)

$$\text{Center of Buoyancy } (C_B) = \frac{Y1V1 + Y2V2 + Y3V3}{V1 + V2 + V3} \qquad (3.9)$$

Y = position of center of buoyancy of each body (taking 0 at bottom of the model)
V = Volume of each body

3. Calculate distance GB

$$GB = C_G - C_B$$

4. Calculate MB

$$MB = \frac{I_{x'x'}}{V_s} \quad \text{(3.10)}$$

$$I_{x'x'} = I_{xx} + (Ad)$$

$$I_{xx} = bh^3/12$$

V = volume of submerge model = 1851.548 cm^3

5. Calculate metacentric height (MG)

MG = MB – GB, Where if MG > 0 it indicates that the structure is stable.

3.6 Experimental Works

3.6.1 Experiment Set Up

Before doing any test, the experimental set up including model, camera and anchors should be put properly.

1. Model: First and foremost, make sure there is no water inside the model. If there is any, discharge the water via two holes located at hull of the model. A water proof sticker will be use to close these holes. The sticker will be glue with silicon gel to make sure no water will comes in via these two holes. A pole – like thing is attached to the topside. This pole is made from cotton butt and the main purpose is to be a reference point for any movement of the model. Besides that, a sticker will be use to indicate the desired draft on the model. This draft point is a line with water surface.

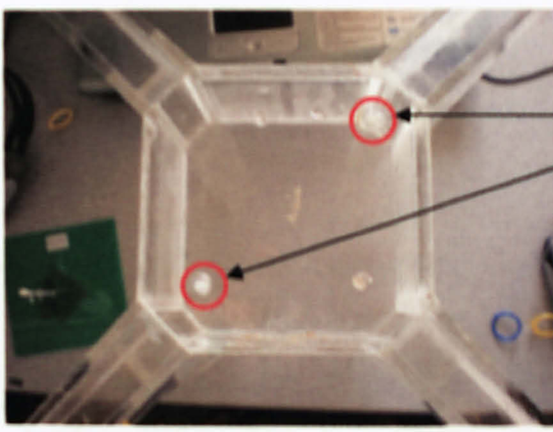

Figure 3.2: Bottom view of hull

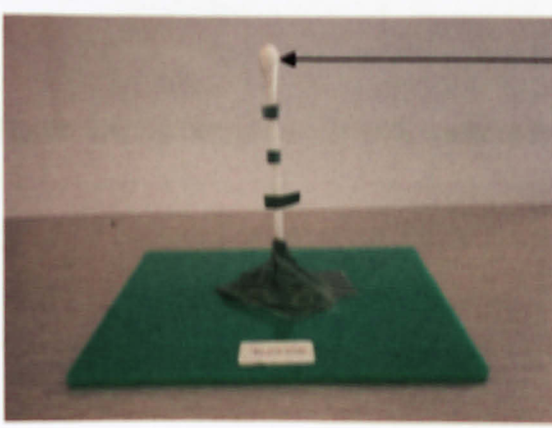

Figure 3.3: Pole on top of topside

2. Tethers and anchors: After model has been set up properly then only, the arrangement of tethers takes place. Tethers will be tied to the model (pad-eye). Arrangement of tethers is essential as it helps the model to behave like the real TLP structure. Tethers should be vertical from the connector (pad-eye). There is a method to make sure the tethers are aligned vertically. The method is, first to arrange the anchors (concrete block 15cm x 15cm x 15cm) by estimating the vertical line connecting two points between tethers and anchors. Then put the model down until it touches the anchor. By referring to the model, adjust all anchors until the hook locates exactly underneath the tethers connector (pad-eye). This way, it is ensure that the tethers are in held vertical by anchors at four different places. By ensuring the tethers are aligned with anchors, it also means that the model is properly set up. After that, fill up the wave tank with water until it reaches water depth of 0.7m.

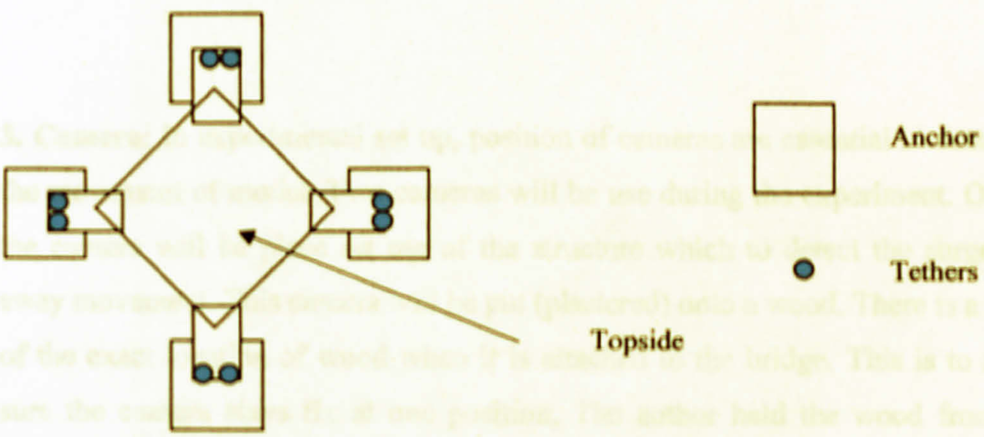

Figure 3.4: Sketch of model with anchors from top view

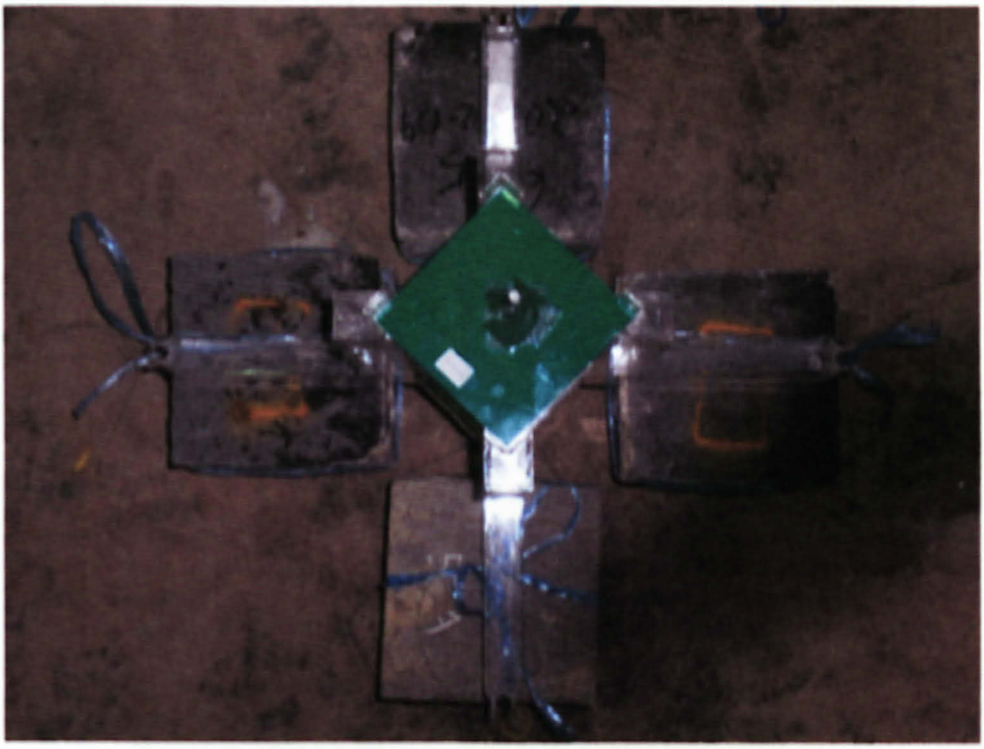

Figure 3.5: Tethers connectors are aligned vertically with anchors.

3. Camera: In experimental set up, position of cameras are essential in detecting the movement of model. Two cameras will be use during the experiment. One of the camera will be place ***on top*** of the structure which to detect the surge and sway movement. This camera will be put (plastered) onto a wood. There is a mark of the exact location of wood when it is attached to the bridge. This is to make sure the camera stays fix at one position. The author held the wood from the bridge. This might caused a slight error in the video clip as the camera position is not fixed. The distance between camera and model (topside) is 0.97 m.

The other will be place at ***side*** of the wave tank where it will be supported by tripod to record tilt, water fluctuation, wave height, wave period and surge. Before recording, the distance between camera and wave tank's glass window should not be too close. A suitable distance should be found in order to get a reliable video where the scale on glass window is also recorded. Both camera records simultaneously.

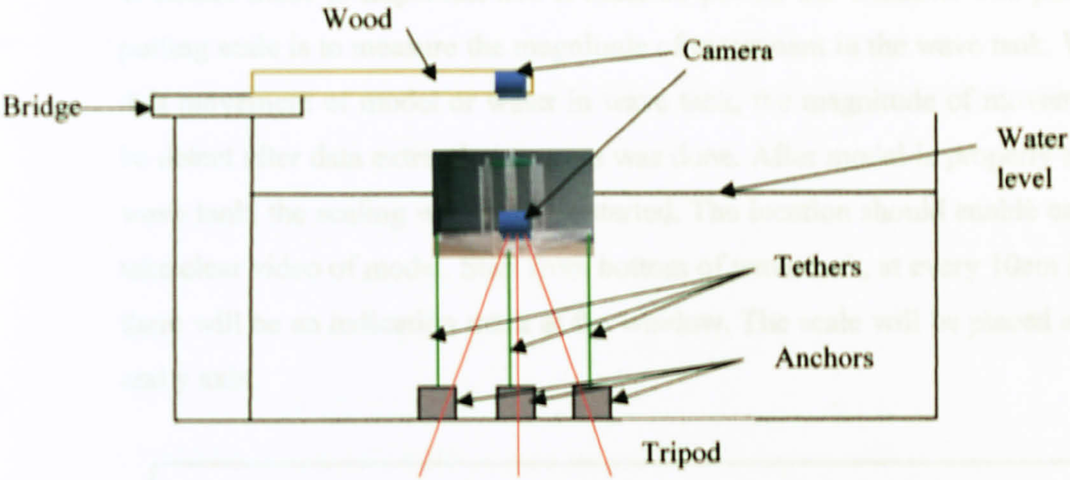

Figure 3.6: Sketches of model in wave tank together with two cameras.

Figure 3.7: Two cameras (top and side) recording the movement of model

4. Scale: Scale is important and it must be put on the window. The purpose of putting scale is to measure the magnitude of movement in the wave tank. Whether it is movement of model or water in wave tank, the magnitude of movement can be detect after data extracting process was done. After model is properly set up in wave tank, the scaling work will be started. The location should enable camera to take clear video of model. Start from bottom of wave tank, at every 10cm interval, there will be an indication mark at the window. The scale will be placed at both x and y axis.

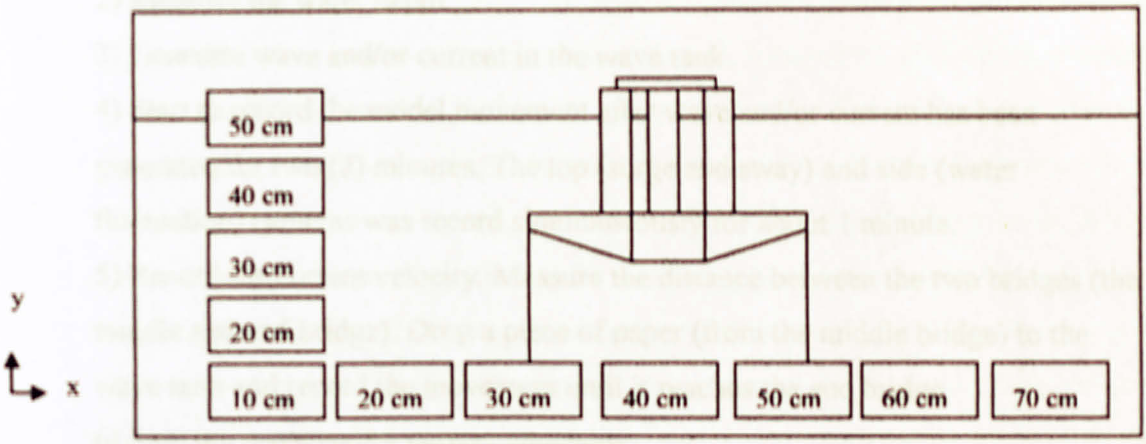

Figure 3.8: Sketch of scale on wave tank's window.

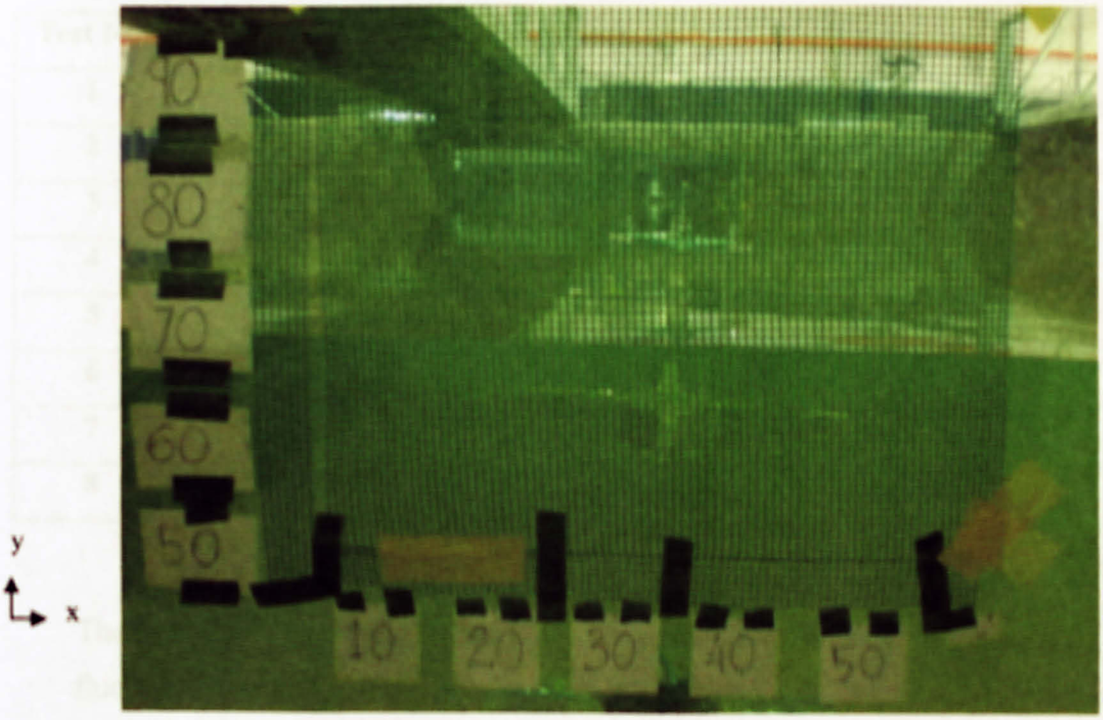

Figure 3.9: Scale together with the model

3.62 Experimental Procedure

Experiments will only starts after models everything has been properly set up. Here are the procedures:

1) Just before the experiment starts, record a ten (10) seconds video of model without any disturbance (free from current and wave). For recording purpose, the model without any disturbance shall be recorded simultaneously. It indicates the neutral position of the model.
2) Measure the water depth.
3) Generate wave and/or current in the wave tank.
4) Start to record the model movement after wave and/or current has been generated for two (2) minutes. The top (surge and sway) and side (water fluctuation) cameras was record simultaneously for about 1 minute.
5) Record the current velocity. Measure the distance between the two bridges (the middle and end bridge). Drop a piece of paper (from the middle bridge) to the wave tank and record the movement until it reaches the end bridge.
6) Stop the wave and/or current generator.
7) Repeat steps 3-6 for other tests. The list of the test:

Test No.	Wave Height (cm)	Current (m/s)	Wave Frequency
1	7.0	-	0.2
2	-	0.3	0.2
3	3.0	0.3	0.2
4	7.0	0.3	0.2
5	3.0	-	0.2
6	-	0.2	0.2
7	3.0	0.2	0.2
8	7.0	0.2	0.2

The first four tests did not measure few parameters such as wave height, water fluctuation, current velocity and water depth. Wave height and water fluctuation cannot be measure because there is not enough indication about these parameters on video. Water depth and current velocity are not measure for the first four tests.

3.6.3 Method of Analysis

In Method of Analysis, there are three main parts where the first part will explain on how to extract data from video. The second part will discuss about the correction factor. Last but not least, the third part will mention on how to measure certain parameter from video.

A) EXRACTING DATA

Extracting information or data from videos that were recorded from laboratory tests is crucial as it gives the real information. A transparent grid which contains boxes of $1mm^2$ is attached in front of computer screen. Then, select and play the desired video. Record the displacement for every second for about 50 seconds. It was done by pausing for each second of the video clips. There is an actual distance (scale) at the left side of the video. This distance indicates the actual distance for the structure. It is important to determine the scale between *video distance* and the actual distance. So any movement or displacement detected and recorded from the video with the help of paper grid, shall be multiply with the scale to get the actual movement.

Figure 3.10: Transparent grid in front of monitor.

As shown in from figure 3.10, A is the *video distance* for the actual 10cm (90-80) distance. By measuring A, a scale can be made to represent the actual distance. For example:

Assuming A is 3cm , the scale will be:

$(1 / A) \times 10 = (1 / 3) \times 10 = 3.33$

The scale is 1:3.33 which means that a movement of 1 cm detected in the video represent 3.33cm actual movement.

If a 2.3 cm displacement detected from *video distance*, it means that the actual displacement is 2.3cm x 3.33 = 7.659cm

B) CORRECTION FACTOR

Correction factor applies to camera positioned on top of the model. There is a distance between the model and the camera. Movement in the video from that camera is not the actual movement. For instance, an object located 10meters away from our eyes moves about 1m, but from our eyes the 1m distance the object has traveled is only about few centimeters.

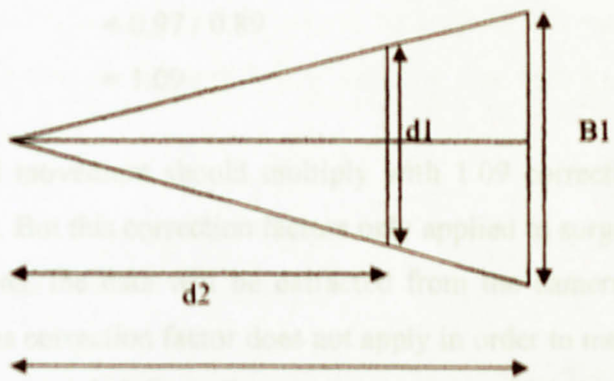

Figure 3.11: Illustration for correction factor

Where;

d1 = video movement

d2 = 0.89 (Distance from camera to cotton butt)

B1 = Actual movement of structure

B2 = 0.97m (Distance from camera to topside)

Correction Factor = B2 / d2

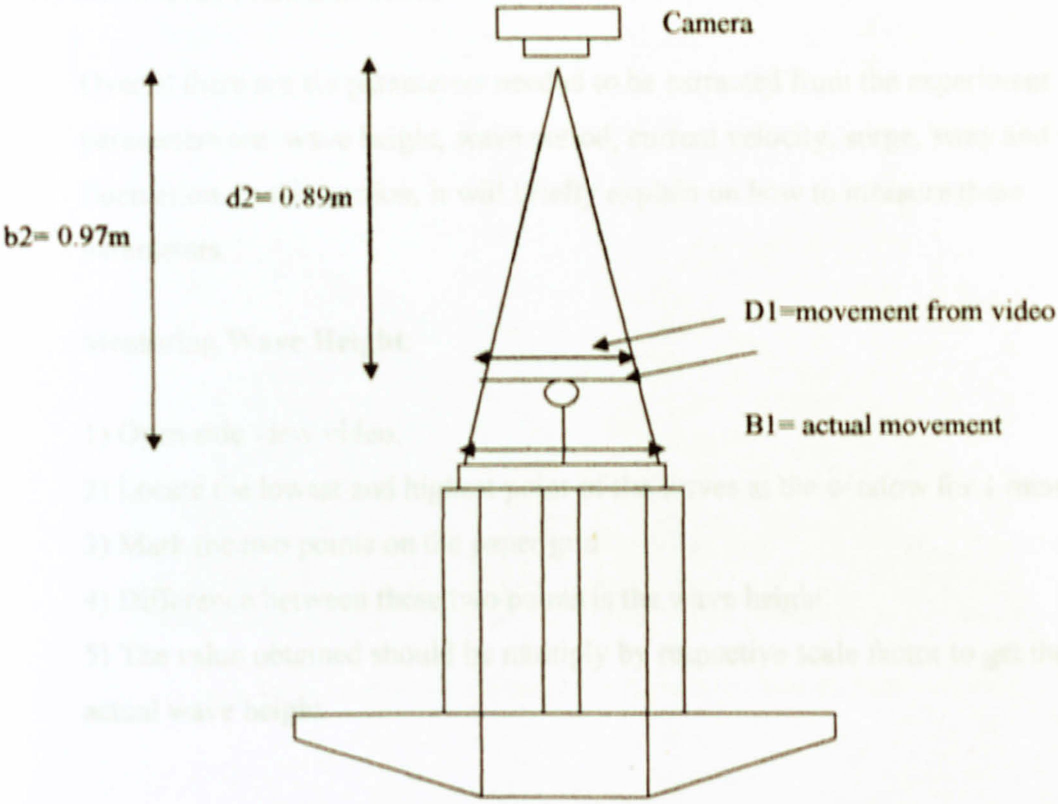

Figure 3.12: Sketch of model with camera to determine the correction factor

Correction Factor = B2 / d2;

= 0.97 / 0.89

= 1.09

The actual movement should multiply with 1.09 correction factor to get the exact movement. But this correction factors only applied to surge and sway motion as these two motions, the data will be extracted from the camera positioned on top of the model. This correction factor does not apply in order to measure wave height or water fluctuation recorded from the second camera which is located at the side of the model.

C) MEASURE PARAMETERS

Overall there are six parameters needed to be extracted from the experiment. The parameters are: wave height, wave period, current velocity, surge, sway and water fluctuation. In this section, it will briefly explain on how to measure these parameters.

Measuring **Wave Height**:

1) Open side view video.

2) Locate the lowest and highest point of the waves at the window for 1 minute.

3) Mark the two points on the paper grid.

4) Difference between these two points is the wave height.

5) The value obtained should be multiply by respective scale factor to get the actual wave height.

Measuring **Wave Period**:

1) Open side view video

2) Locate the wave crest point for each wave at the window.

2) Record how long it takes to have 10 cycle of wave crest.

3) Determine the wave period by dividing time recorded with number of wave crest cycle.

Measuring **Current Velocity**.

1) Decide a distance to measure the wave velocity. For this experiment, distance between two (2) bridges (middle and end bridges).

2) Measure the distance between these bridges.

3) Drop any floating object (e.g. paper clip) from the middle bridge into wave tank when wave and/or current is generated.

4) Record video and follow the movement of paper until it reaches the end bridge.

5) Determine the wave celerity by dividing the distance it moves with time taken to travel from middle bridge to end bridge.

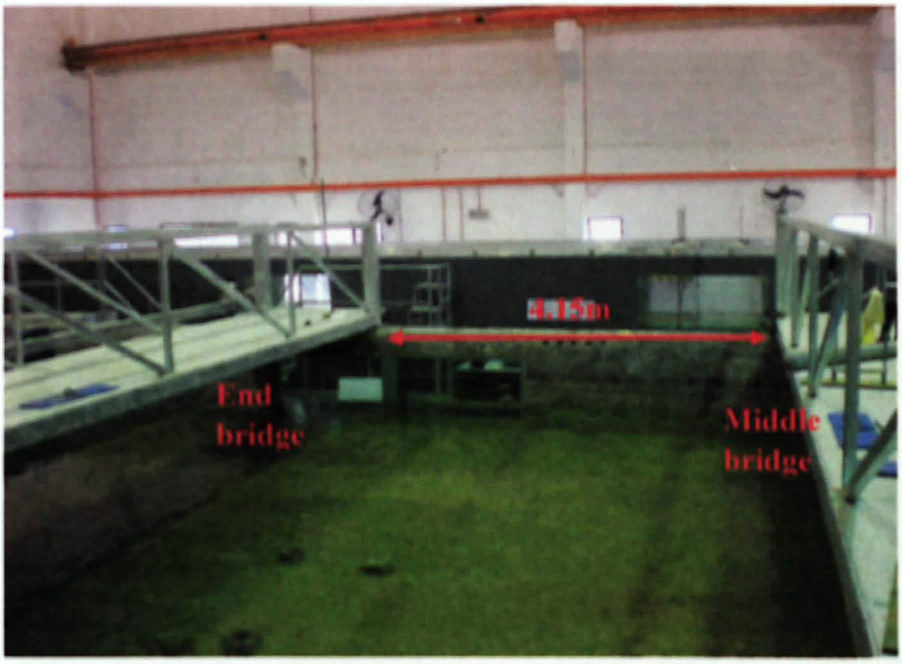

Figure 3.13: Distance between bridges to calculate current velocity

Measuring **Surge & Sway**:

1) Open video from top view.

2) Locate the maximum surge (vertical) & sway (horizontal) movement from the video.

3) Locate the surge and sway movement for each second for 50seconds.

4) Multiply the recorded movement with scale to get the actual movement.

5) Multiply the actual movement with correction factor to get the exact movement.

Measuring **Water Fluctuation**:

1) Open video clip from side view.

2) Locate and record the water level at one (1) point for each second for 50 seconds.

3) All values for each seconds should be multiply with respective test's scale.

Measuring **Water Depth**:

1) Measure height of the water using measuring tape.

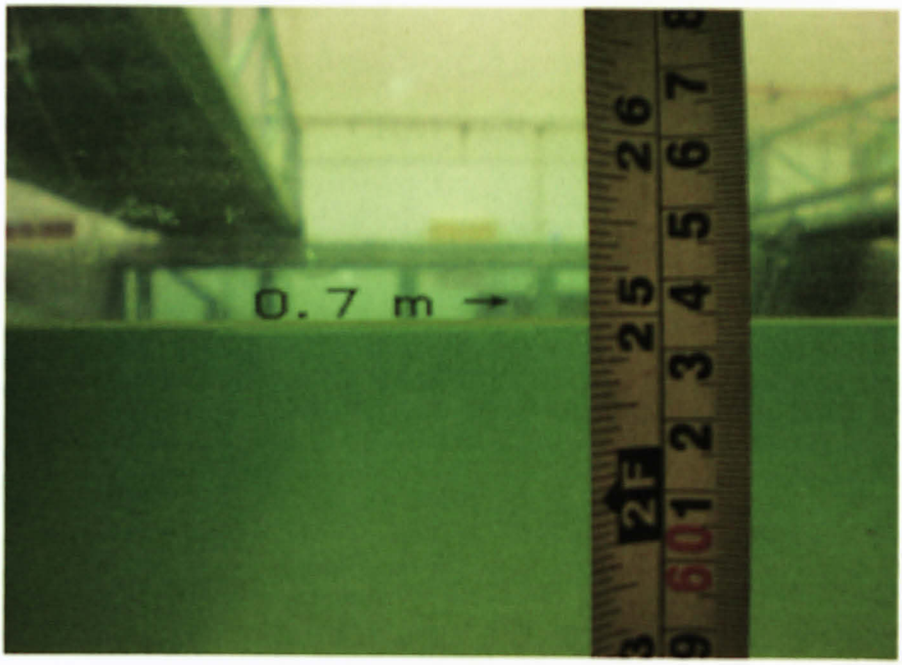

Figure 3.14: Measuring the water depth

After all data or information is successfully extracted from videos or pictures, result on sway, surge and water fluctuation shall be plot in a graph. Each test will have its own graph.

CHAPTER 4

RESULT & DISCUSSION

4.1 Model of Tension leg Platform (TLP)

4.1.1 Dimension

After careful calculation was made to decide the scale to be use, it was decided to take the scale as 200 for this Tension Leg Platform (TLP) modeling purpose. But not all parameters were scaled down using this scale as the laboratory does not have the necessary equipment for such thing. Water depth and tethers, tethers stiffness are the parameters not being scale down. Water depth and length of tethers cannot is impossible to scale down as the depth of wave tank is small. Even if the depth is scale down accordingly, the impact will not be the same as the actual TLP. Regarding the stiffness of tethers, even tough by calculation it is enable to scale down, but it is hard to find a suitable material where it has the same scale down stiffness. Summarization for the TLP model is:

- Column Height x Breadth x Width; 19.5cm x 3.5cm x 2.8cm
- Hull Height; 6.4 cm
- Total Height; 26 cm
- Water Depth; 70 cm
- Draft; 18 cm
- Tethers; 8 tethers
- Total Weight; 1.2 kg
- Tendon Support Structure (including column); 16.5 cm
- From one end to another end; 45.1 cm

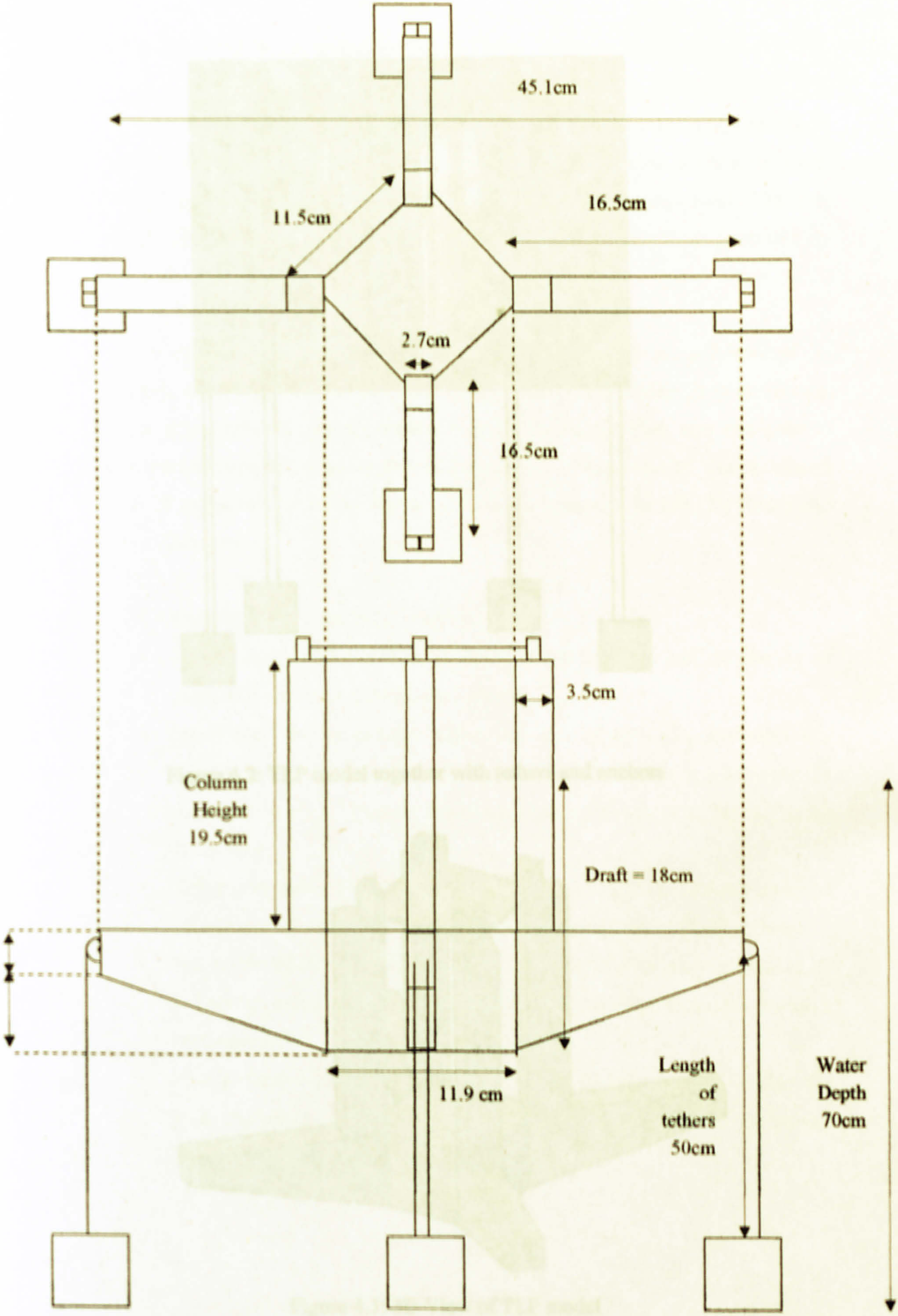

Figure 4.1: Top and Side View of model

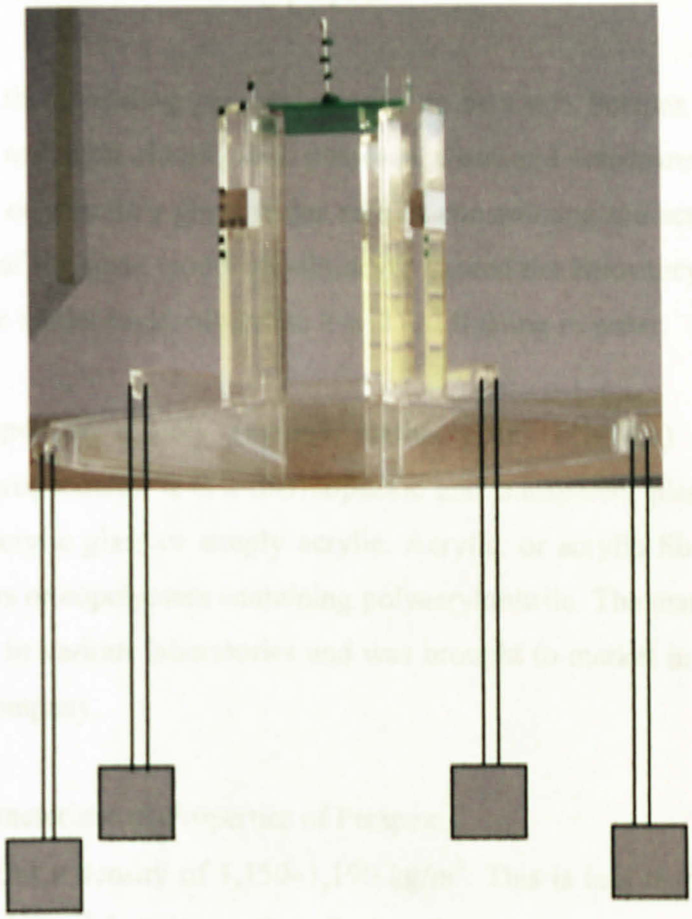

Figure 4.2: TLP model together with tethers and anchors

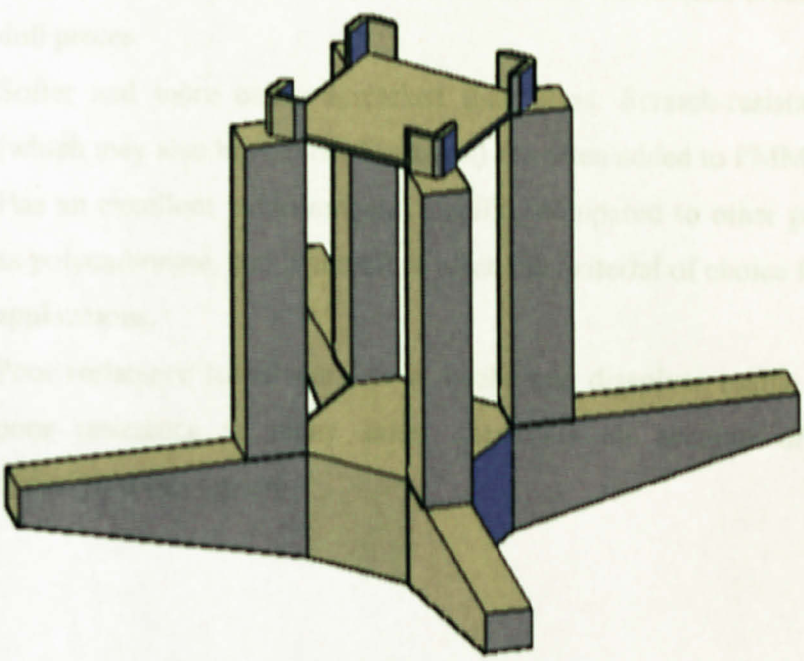

Figure 4.3: 3D View of TLP model

4.1.2 Material for modeling purpose

For this modeling purpose, material to be use is Perspex. Perspex has a light weight and light density but posses a clear and transparent surface as glass. Weight of materials plays major role in constructing the scale model. The total weight of the scale model should never exceed the Buoyancy force generated by the scale model itself, otherwise it will not floating in water.

Perspex is a poly (methyl methacrylate) (PMMA) or poly(methyl 2-methylpropenoate). It is a thermoplastic and transparent plastic. It is commonly called acrylic glass or simply acrylic. Acrylic, or acrylic fiber, can also refer to polymers or copolymers containing polyacrylonitrile. The material was developed in 1928 in various laboratories and was brought to market in 1933 by Rohm and Haas Company.

Characteristic or Properties of Perspex:

- Has a density of 1,150–1,190 kg/m^3. This is less than half the density of glass, and similar to that of other plastics.
- Has a good impact strength higher than that of glass or polystyrene, but significantly lower than that of polycarbonate or engineering polymers. In the majority of applications, it will not shatter but instead breaks into large dull pieces.
- Softer and more easily scratched than glass. Scratch-resistant coatings (which may also have other functions) are often added to PMMA sheets.
- Has an excellent environmental stability compared to other plastics such as polycarbonate, and is therefore often the material of choice for outdoors applications.
- Poor resistance to solvents, as it swells and dissolves easily. It also has poor resistance to many other chemicals on account of its easily hydrolyzed ester group

Besides than perspex, other two materials that were used for prototype is the monoline and plastic ring. It is a fishing rail which can hold a weight of 50lb (approximately 22.68kg). It acts as tethers for the structure. A high strength fishing rail which can hold quite a large weight (more than 20kg) is very important to the structure. It will not break during laboratory testing and it can hold the structure firmly. If it can only hold a small weight which means it can only withstand little forces, then the tension force caused by the movement of the model during laboratory test will break the tethers.

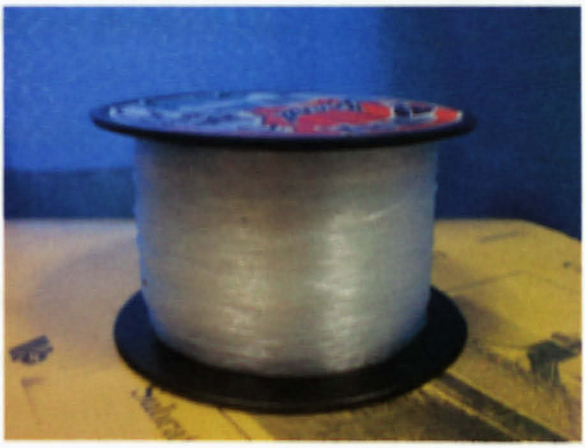

Figure 4.3: Monoline fishing rail.

Figure 4.4 Plastic ring.

4.2 Pre Tension in Tethers:

Pre Tension in Tethers (P) = Buoyancy (B) – Weight of Model (W)..................(3.1)

Known parameters;
Weight = 1.2 kg or 11.77 N
Sea water density = 1030 kg/m^3;
Gravity = 9.807 m/s^2

Buoyancy (B) = Hull Buoyancy (B_H) + Column Buoyancy (B_C) + Tendon Support Structure Buoyancy (B_T)..(3.2)

Buoyancy of Columns (B_C)

No of columns x height x breadth x width x sea water density x gravity.................(3.3)

Buoyancy of hull (B_H)

Volume of hull x sea water density x gravity..(3.4)

Buoyancy of Tendon Support Structure (B_T)

4 x volume of tendon support structure x sea water density x gravity.................(3.5)

By substituting equation 3.2 into 3.1;

Pre Tension in Tethers (P) = $(B_C + B_H + B_T)$ – (W)..................................(3.6)

$= (B_C + B_H + B_T) - 11.77\text{N}$

From equation 3.3, Buoyancy of Columns (B_C)

$= 4 \times 0.115 \times 0.035 \times 0.027 \times 1030 \times 9.807$

$= 4.39$ N

From equation 3.4, Buoyancy of Hull (B_H)

$= [0.102^2 - 2(0.019^2)] \times 0.064 \times 1030 \times 9.807$

$= 6.26$ N

From equation 3.5, Buoyancy of Tendon Support Structure (B_T)

$= 4 \times [0.5 \times 0.165 \times (0.064 + 0.024) \times 0.027] \times 1030 \times 9.807$

$= 7.92$ N

From equation 3.2, Total Buoyancy, B

$= 4.39 + 6.26 + 7.92$

$= 18.57$ N

From Equation 3.6, Pretension in tethers (P) $= (B_c + B_T + B_H) - 11.77$ N

$= 18.57 \text{ N} - 11.77 \text{ N}$

$= 6.8$ N

From Equation 3.7, Tension in each tether (T) = P / No of tethers

$= 6.8 \text{ N} / 8$

$= 0.85$ N or 0.08667 kg

4.3 Hydrostatic Stability

Three main components that are crucial in determining the stability of floating structure are Metacenter (C_M), Center of Gravity (C_G) and Center of Buoyancy (C_B). For this model, all these points are located at the center of the model (origin at x and z axis). To determine the stability of the model these are the steps

Due to the symmetrical shape of the model, the structure was divided into 4 parts to determine (C_G) and (C_B).

1. Find the location of Center of Gravity, (C_G) (in y-axis)

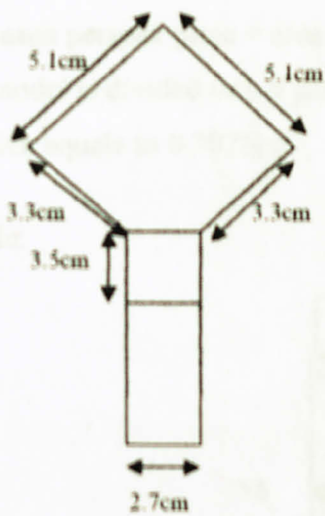

Figure 4.5: Plan View (1/4 of model)

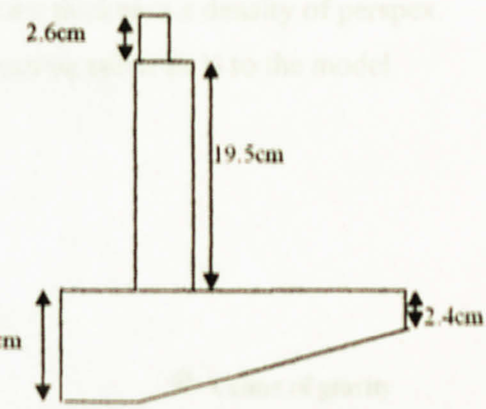

Figure 4.6: Side View (1/4 of model)

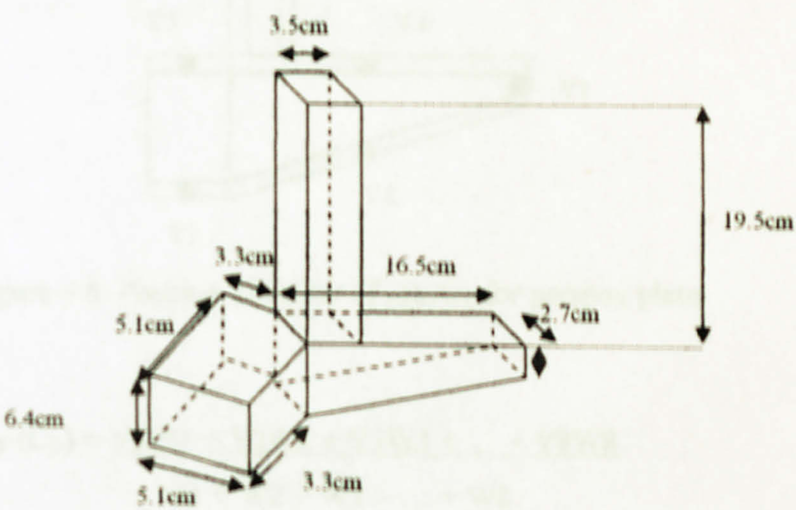

Figure 4.7: 3D View (1/4 of model)

The model were constructed using perspex with 4mm thickness; density of perspex is 1190 kg/m^3

Position of center of gravity located in the center of perspex plate for rectangular shape.

Eq. (3.8) Center of Gravity (C_G) = $\dfrac{Y1W1 + Y2W2 + Y3W3 + \ldots + YnWn}{W1 + W2 + W3 + \ldots + Wn}$

Y = position of center of gravity for each perspex plate. (from bottom of the model)
W = weight of each perspex plate

Weight of each perspex plate = area of perspex plate x thickness x density of perspex. Since the model is divided into 4 parts, the weight can be taken as ¼ to the model weight which equals to 0.3075kg.

2D example:

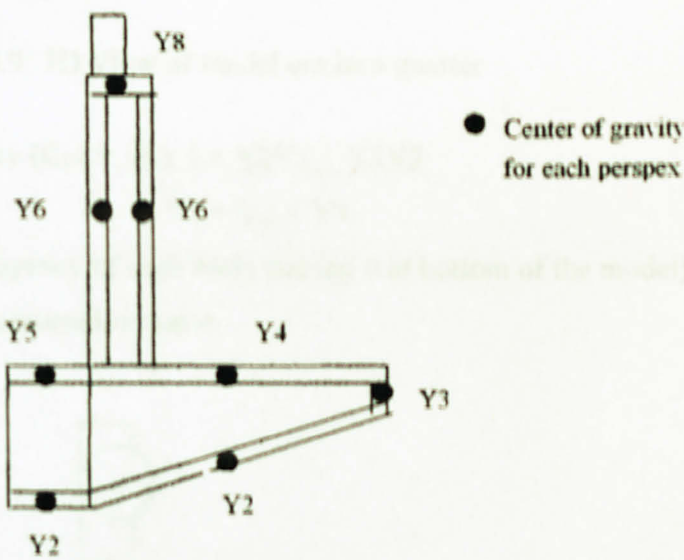

Figure 4.8: Position of center of gravity for perspex plate

Center of Gravity (C_G) = $\dfrac{Y1W1 + Y2W2 + Y3W3 + \ldots + Y8W8}{W1 + W2 + W3 + \ldots + W8}$

By using the same concept, based on equation 3.8, Center of Gravity (C_G)

$= \dfrac{0.0214313}{0.3075}$

$= 0.0697\text{m}$

2. Find the location of Center of Buoyancy (C_B) (in y-axis)

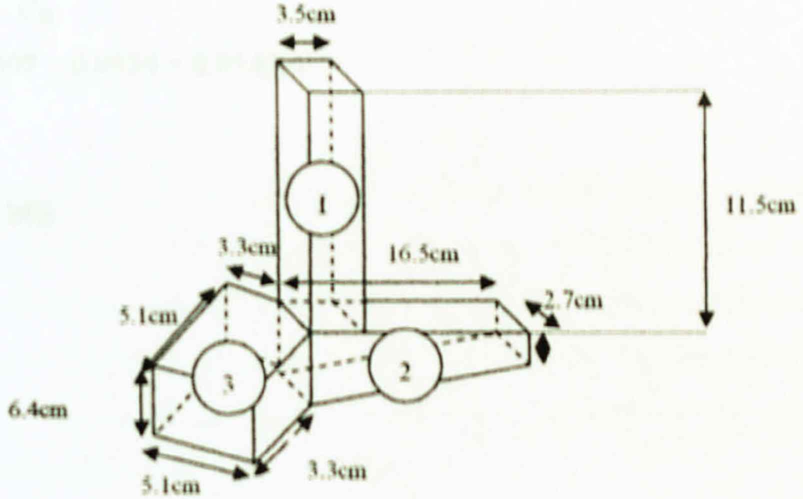

Figure 4.9: 3D View of model cut into quarter

Eq. (3.9) Center of Buoyancy (C_B) $= \dfrac{Y1V1 + Y2V2 + Y3V3}{V1 + V2 + V3}$

Y = position of center of buoyancy of each body (taking 0 at bottom of the model)

V = Volume of each body immersed in water

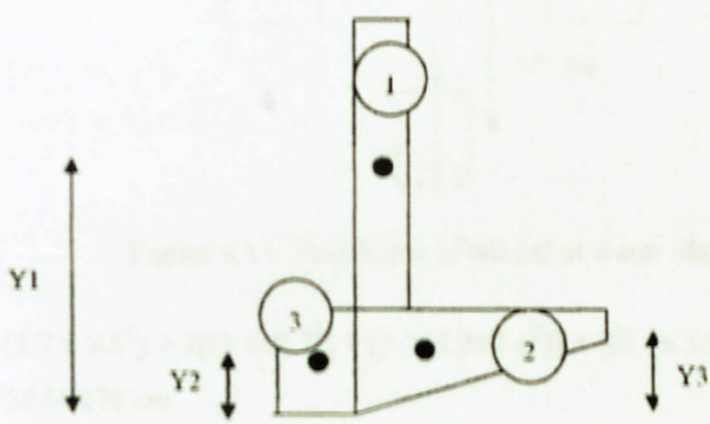

Figure 4.10: Position of center of buoyancy for each part

Referring to the Figure 4.8 and applying equation 3.9,

$$C_B = \frac{(0.1215 \times 0.000108) + (0.0375 \times 0.000196) + (0.032 \times 0.0001561)}{0.000108 + 0.000196 + 0.0001561}$$

$C_B = 0.0554m$

3. Calculate distance GB

$GB = C_G - C_B$

$= 0.0697 - 0.0554 = 0.0143m$

4. Calculate MB

$$MB = \frac{I_{x'x'}}{V_s}$$

$I_{x'x'} = I_{xx} + (Ad)$

$I_{xx} = bh^3/12$

V = volume of submerge model = 1851.548 cm^3

(from equation 3.10)

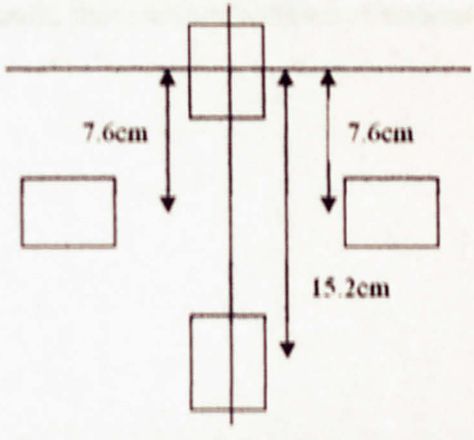

Figure 4.11: Plan View of Model at water plane area

$I_{x'x'} = (2.7 \times 3.5^3) + 2[(3.5x2.7^3) + (2.7x3.5x7.6^2)] + [(2.7x\ 3.5^3) + (2.7x3.5x15.62^2)]$

$= 3644.298\ cm^4$

MB = 3644.298 / 1851.548 = 1.97cm

5. Calculate metacentric height (MG)

MG = MB – GB, Where if MG > 0 it indicates that the structure is stable.

MG = 1.97m – 1.43cm = 0.54cm = stable

4.4 Laboratory Test Result

As mention in 3.2.4 Laboratory Test, there are three parts of the test. Each test was using two cameras. The first camera will be recording the side of model, which can measure the surge movement. The other camera was located on top of the model to record the sway movement of the model. In this laboratory test result and discussion, it will show the result for surge and sway displacement according to its test. Overall eight (8) tests were conducted.

Result & Discussion

For laboratory test result, there are six parameters measured which are:

1. Wave Height.
2. Wave Period.
3. Water Depth.
4. Maximum Surge.
5. Maximum Sway.
6. Current Velocity.

The first four tests did not measure few parameters such as wave height, water fluctuation, current velocity and water depth. Wave height and water fluctuation cannot be measure because there is not enough indication about these parameters on video. Water depth and current velocity are not measure for the first four tests. Overall, eight experiments were conducted with different wave height and current.

Test 1: Wave Height 7cm with No Current

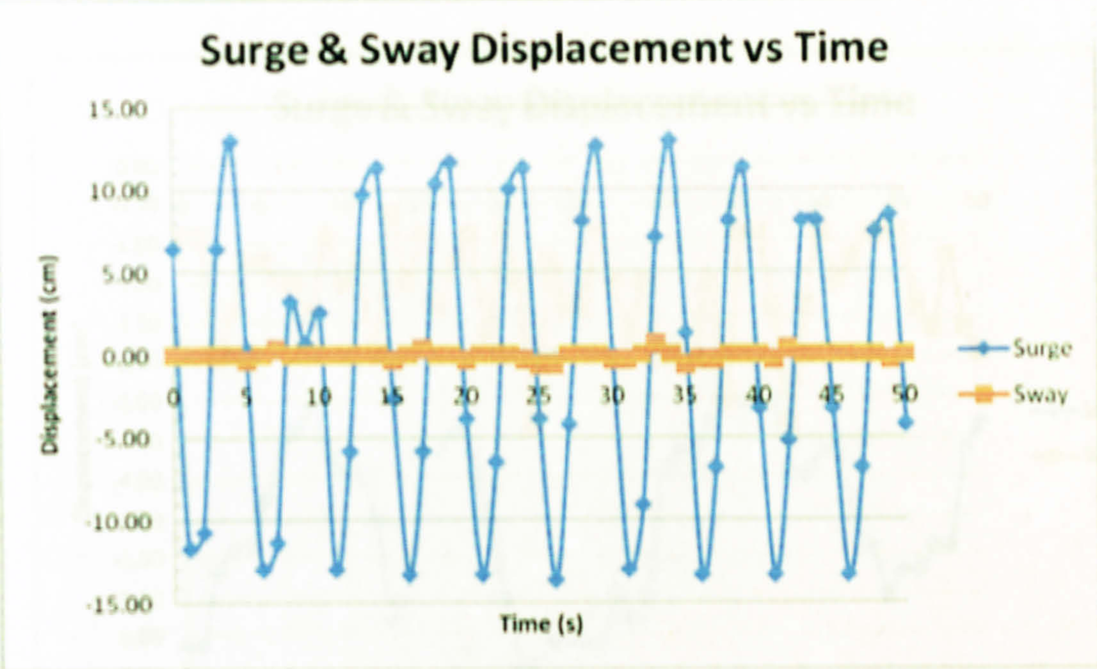

Figure 4.12: Graph of surge and sway displacement vs. time (wave 7cm)

Table 4.1: Test result for model when it was tested with wave height 7cm:

Parameter	Theory	Actual (Measurement)
Wave Height	7cm	-
Wave Period	5s	5.12 s
Water Depth	70cm	-
Maximum Surge	-	27.52cm
Maximum Sway	-	0.97cm
Current Velocity	-	-

Test 2: Current 0.3m/s with No Wave

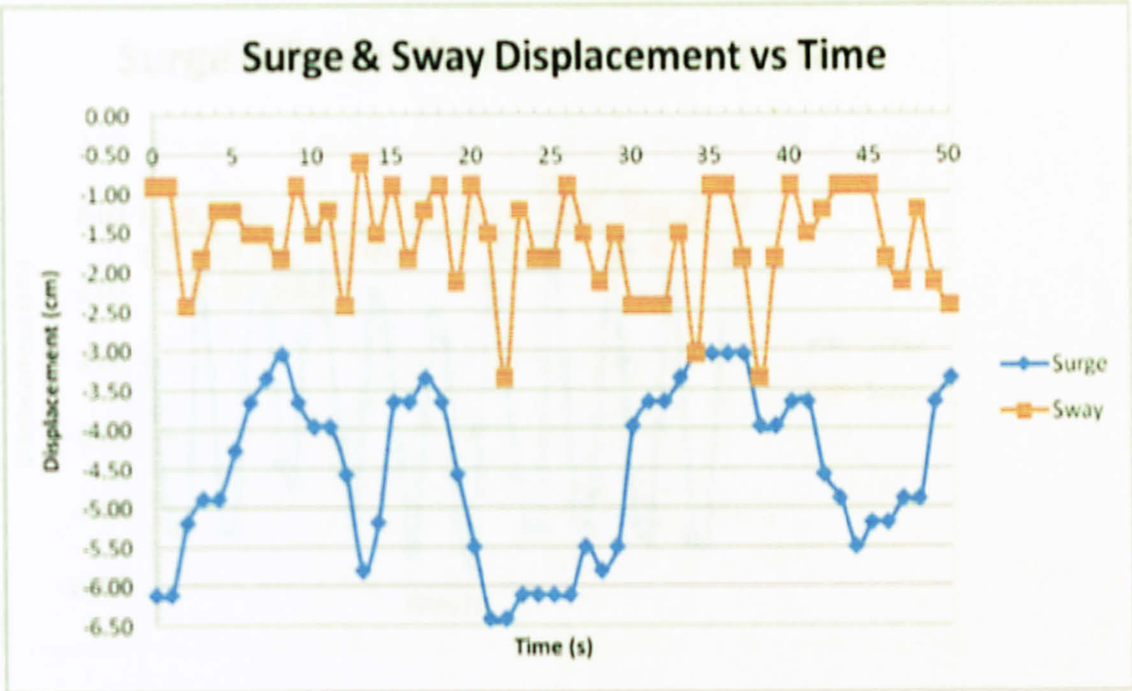

Figure 4.13: Graph of surge and sway displacement vs. time (current 0.3)

Table 4.2: Test result for model when it was tested with current 0.3m/s:

Parameter	Theory	Actual (Measurement)
Wave Height	-	-
Wave Period	-	5.06s
Water Depth	70cm	-
Maximum Surge	-	3.6cm
Maximum Sway	-	2.14cm
Current Velocity	0.3m/s	-

Test 3: Current 0.3m/s with Wave Height 3cm

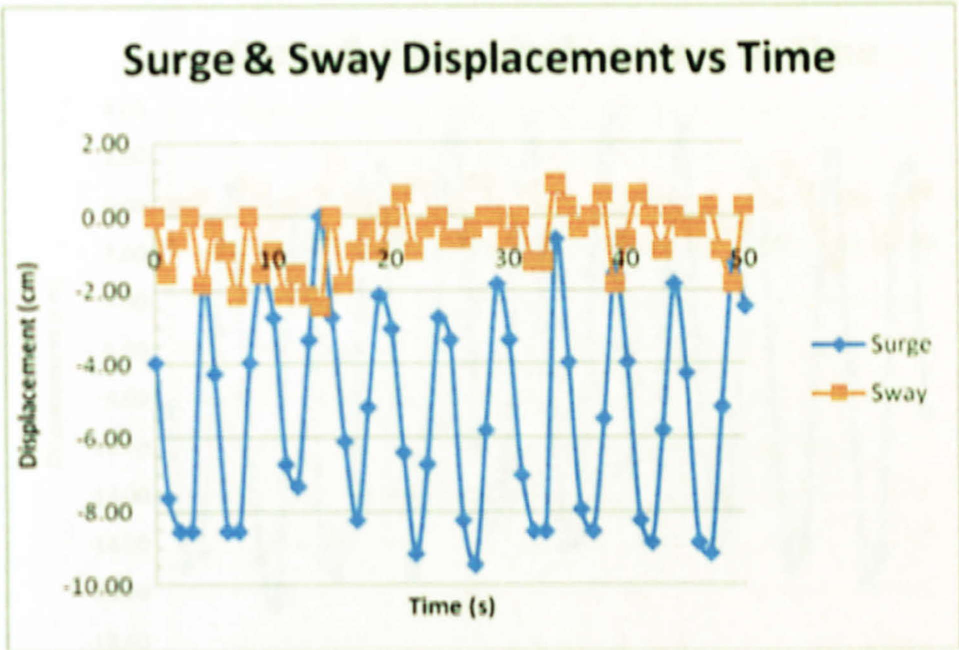

Figure 4.14: Graph of surge and sway displacement vs. time (current 0.3 wave 3cm)

Table 4.3: Test result for model when it was tested with current 0.3m/s wave height 3cm

Parameter	Theory	Actual (Measurement)
Wave Height	3cm	3.42cm
Wave Period	5s	5.1 s
Water Depth	70cm	-
Maximum Surge	-	10.7cm
Maximum Sway	-	3.66cm
Current Velocity	0.3m /s	-

Test 4: Current 0.3m/s with Wave Height 7cm

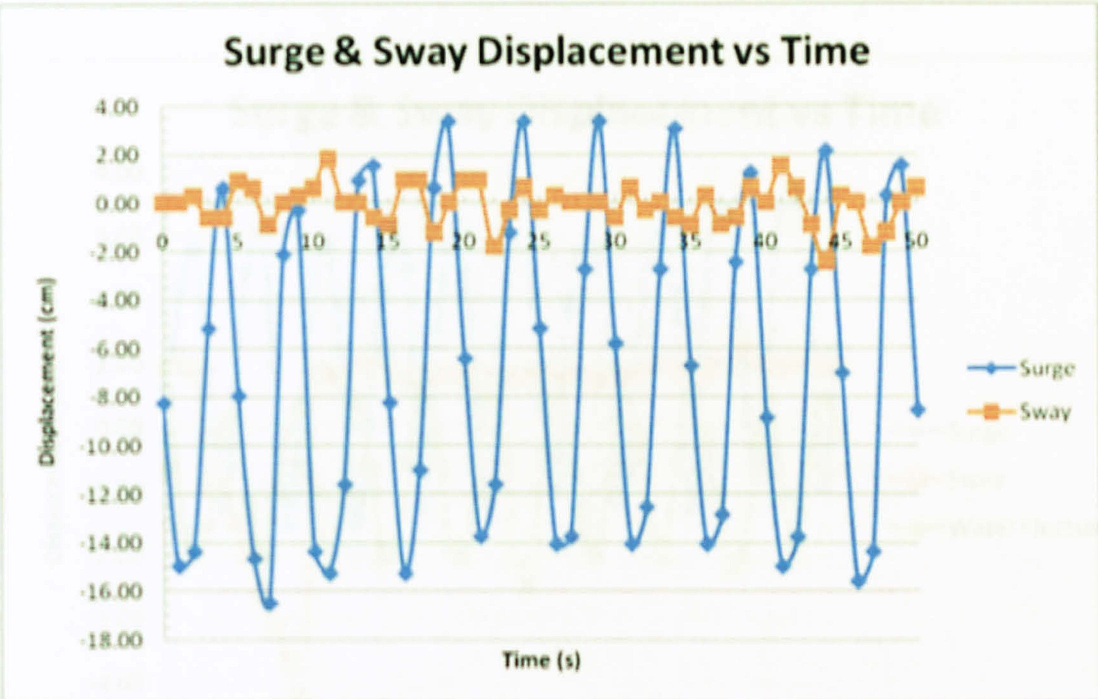

Figure 4.15: Graph of surge and sway displacement vs. time (current 0.3 wave 7cm)

Table 4.4: Test result for model when it was tested with current 0.3m/s wave height 7cm:

Parameter	Theory	Actual (Measurement)
Wave Height	7cm	-
Wave Period	5s	5.0s
Water Depth	70cm	-
Maximum Surge	-	20.75cm
Maximum Sway	-	4.27cm
Current Velocity	0.3m/s	-

Test 5: Wave Height 3cm with No Current

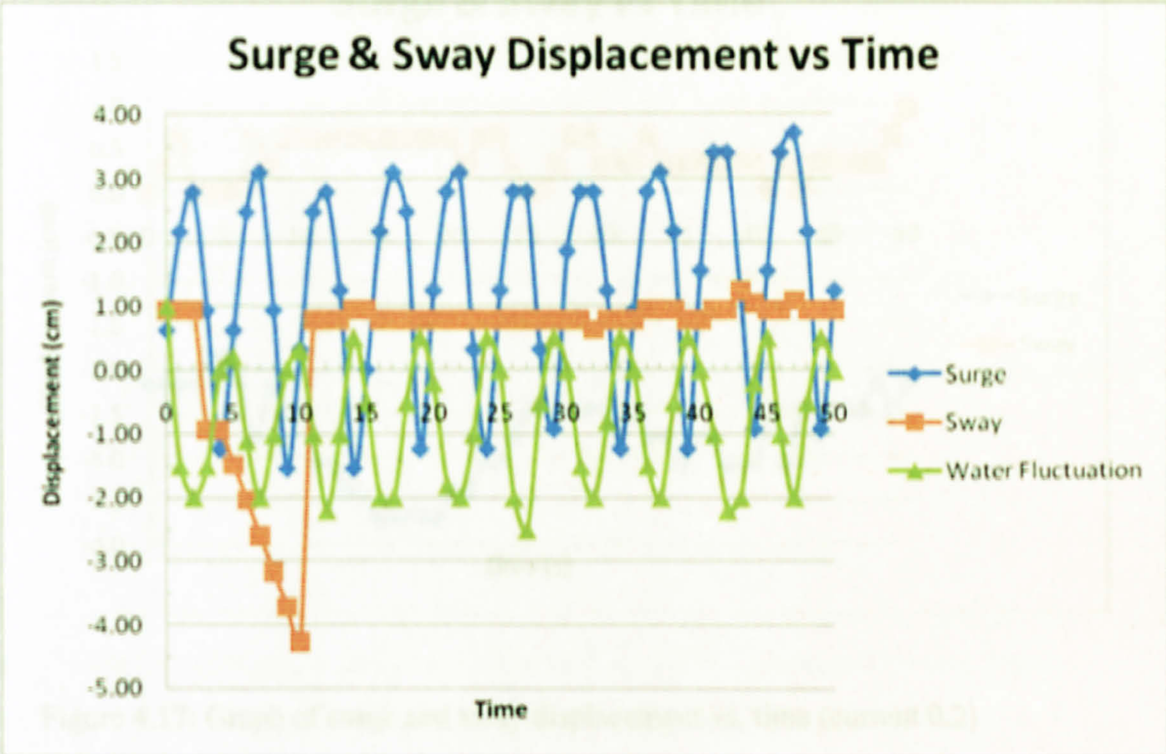

Figure 4.16: Graph of surge & sway displacement vs. time (wave 3cm)

Table 4.5: Test result for model when it was tested with current 0.2m/s wave height 3cm

Parameter	Theory	Actual (Measurement)
Wave Height	3cm	3.42cm
Wave Period	5s	5 s
Water Depth	70cm	68.3cm
Maximum Surge	-	4.02cm
Maximum Sway	-	1.24cm
Current Velocity	0.2m/s	0.148m/s

Test 6: Current 0.2m/s with No Wave

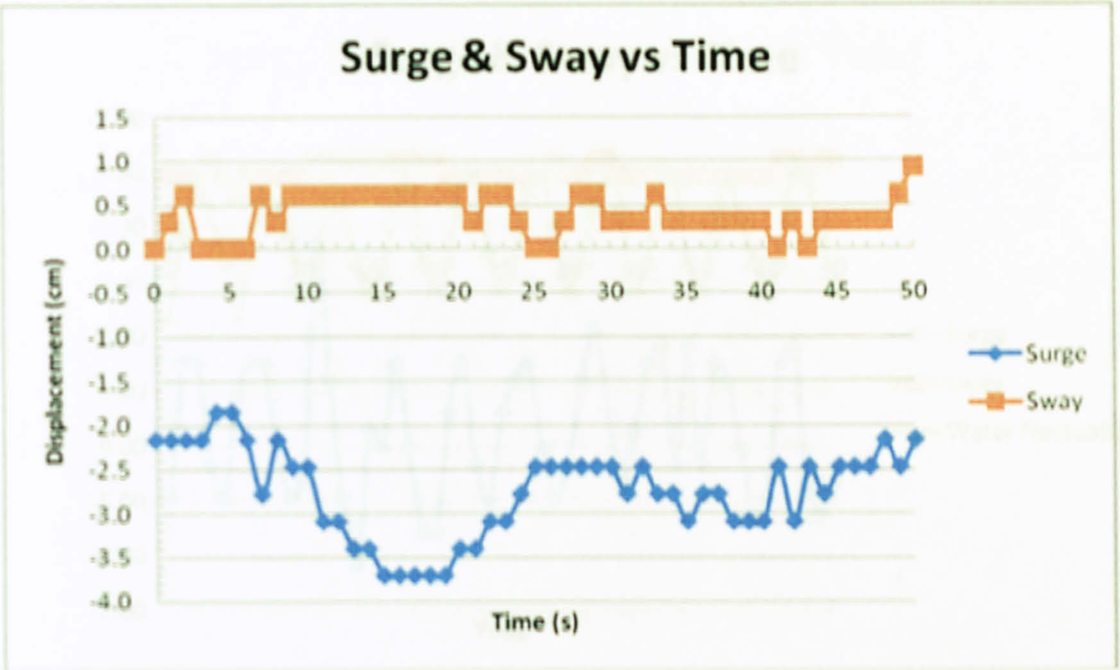

Figure 4.17: Graph of surge and sway displacement vs. time (current 0.2)

Table 4.6: Test result for model when it was tested with current 0.2m/s

Parameter	Theory	Actual (Measurement)
Wave Height	-	-
Wave Period	5s	5s
Water Depth	70cm	68.3cm
Maximum Surge	-	2.17cm
Maximum Sway	-	0.93cm
Current Velocity	0.2m/s	0.148m/s

Test 7: Current 0.2m/s with Wave Height 3cm

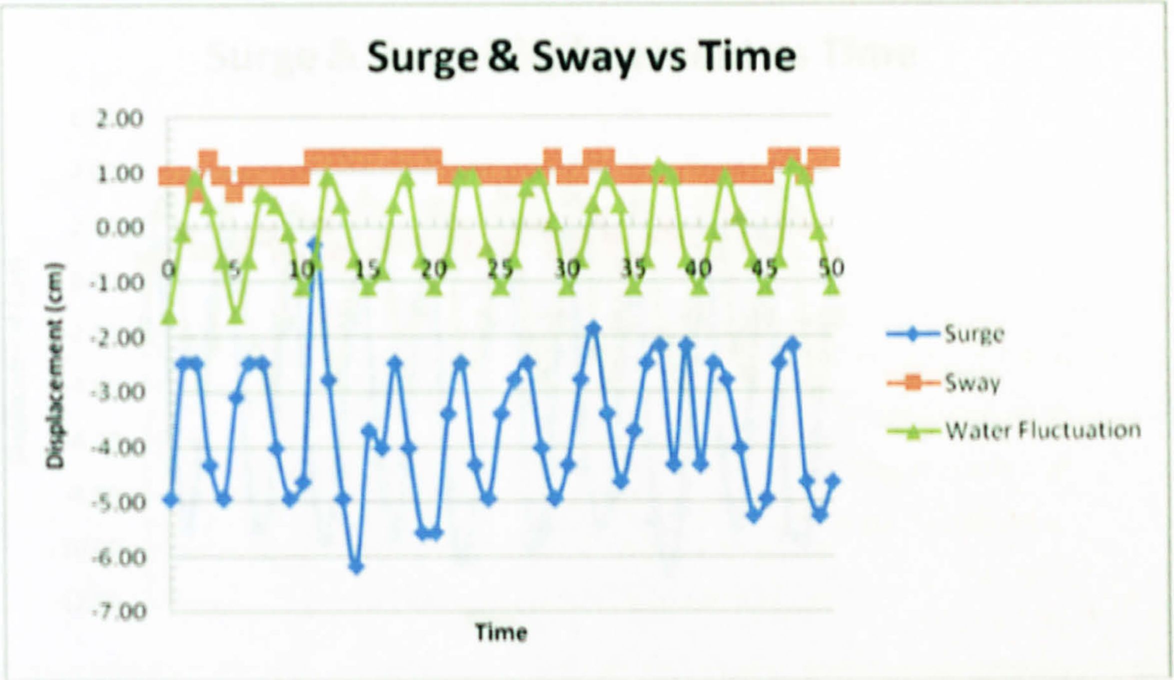

Figure 4.18: Graph of surge and sway displacement vs. time (current 0.2 wave 3cm)

Table 4.7: Test result for model when it was tested with current 0.2m/s wave height 3cm

Parameter	Theory	Actual (Measurement)
Wave Height	3cm	3.16cm
Wave Period	5s	5.12s
Water Depth	70cm	68.3cm
Maximum Surge	-	4.02cm
Maximum Sway	-	1.24cm
Current Velocity	0.2m/s	0.148m/s

Test 8: Current 0.2m/s with Wave Height 7cm

Figure 4.19: Graph of surge and sway displacement vs. time (current 0.2 wave 7cm)

Table 4.8: Test result for model when it was tested with current 0.2m/s wave height 7cm:

Parameter	Theory	Actual (Measurement)
Wave Height	7cm	7.5cm
Wave Period	5s	5.06s
Water Depth	70cm	68.3cm
Maximum Surge	-	11.45cm
Maximum Sway	-	1.86cm
Current Velocity	0.2m/s	0.143m/s

After comparing all these eight (8) experiments:

Maximum surge: 27.52cm. The maximum surge occurs when there is 7cm wave height generated in the wave tank with no current.

Maximum sway: 4.27cm. The maximum sway occurs in a presence of current 0.3m/s and wave height of 7cm.

It can be found that wave the magnitude of surge is highly influenced by wave when there is no current. Magnitude of surge will increase when wave height is increase. On the other hand, for sway movement, the combination of the bigger wave and current is the likely cause for a high magnitude for sway movement.

Parameter	Laboratory test	Conversion to real value	Allowable movement
Max. Surge	27.52cm	55.04 m	10 – 12 m
Max. Sway	4.27cm	8.54 m	5- 6 m

In the real world, for the model that was tested with various wave heights and currents, the maximum surge is 55.04m and maximum sway is 8.54 m. These two values are extreme for TLP. It is expected that the values will be different and there will be no 100% match. The area which may contributes to this extreme value for surge and sway movement are:

1) Tethers do not have the same stiffness with the actual TLP. Even if the stiffness is successfully scale down, it is difficult to have a material which has the same scale and is feasible for this project.

2) The model tested in wave tank only tested with random wave while in the real world, there is no such thing as regular wave.

3) Wave is not being scale down. The movement of model is contributed by the wave energy. The energy from wave in the tank is not the same with the real world even if we manage to scale down the wave.

CHAPTER 5

CONCLUSION

The work steps from research, scale modeling, construction of model, laboratory test are essentials to achieve goal of this project. In every steps, it describe on how it works to accomplish this project. Analysis of a structure is important to determine the behavior of a real structure and the laboratory test that was conducted help us to understand more about tension leg platform (TLP) when hit by waves and/or currents. But prior to the analysis, a model which takes into account every aspect such as scaling down to a feasible model to be constructed is important either. Without the accurate scale down model, the model can not be compared to the real structure.

From the laboratory result, the test confirmed that there is no heave movement of TLP. The sway and surge test result shows that most of the time that the sway and surge movement is directly proportional to the wave height. It means that if wave height is high then the sway and surge movement will increase. But when combining current and wave, it does not necessarily increase the sway and surge movement. It depends on where is the direction of current and wave when travelling to TLP. If they travel in the same direction, the effect will be far greater, but when they travel facing each other, the effect will be smaller. To conclude the project, these two movements are essential to be predicted and analyzed because by analyzing it, it will give more stability to TLP structure.

CHAPTER 6

RECOMMENDATION

For this project, it is good to conduct much more laboratory test in order to really understand the behavior of tension leg platform (TLP). The TLP model should be tested by varying the wave height, current, wave celerity from small, medium and also high.

Besides to get a better view of sway movement of the model, it is best to find a way on how to record video from top of the wave tank. A camera with no movement will lessen the burden in extracting info of the model movement.

In terms of modeling, all dimensions of the model together with the wave mechanics data should be scale down and using the same scale. Do not leave any parameter or wave mechanics data without scaling it. Try to scale down the water depth and tethers if applicable

For model tethers, it is better to have a model which has the same stiffness with the actual tethers. The model will behave just like the actual TLP.

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http://www.offshore-technology.com/projects/baldpate/

[6] "Development of the Prince Field" (2002), J.R. Koon, MODEC International LLC, Bart Heijermans, El Paso Energy Partners, L.P, P.G. Wybro, SEA Engineering, Inc.

APPENDICES

1.0 Result for Surge & Sway Movement

2.0 Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994).

3.0 Development of the Prince Field" (2002), J.R. Koon, MODEC International LLC, Bart Heijermans, El Paso Energy Partners, L.P, P.G. Wybro, SEA Engineering, Inc.

Appendix 1.0 Result for Surge & Sway Movement

Test 1: Current 0.3 No Wave - results are in cm

Surge

	CURRENT 0.3 ; WAVE HEIGHT 0		
time (s)	Video	Real Data	Real Data x Correction Factor
0	0.00	-5.60	-6.10
1	0.00	-5.60	-6.10
2	0.30	-4.76	-5.19
3	0.40	-4.48	-4.88
4	0.40	-4.48	-4.88
5	0.60	-3.92	-4.27
6	0.80	-3.36	-3.66
7	0.90	-3.08	-3.36
8	1.00	-2.80	-3.05
9	0.80	-3.36	-3.66
10	0.70	-3.64	-3.97
11	0.70	-3.64	-3.97
12	0.50	-4.20	-4.58
13	0.10	-5.32	-5.80
14	0.30	-4.76	-5.19
15	0.80	-3.36	-3.66
16	0.80	-3.36	-3.66
17	0.90	-3.08	-3.36
18	0.80	-3.36	-3.66
19	0.50	-4.20	-4.58
20	0.20	-5.04	-5.49
21	-0.10	-5.88	-6.41
22	-0.10	-5.88	-6.41
23	0.00	-5.60	-6.10
24	0.00	-5.60	-6.10
25	0.00	-5.60	-6.10
26	0.00	-5.60	-6.10
27	0.20	-5.04	-5.49
28	0.10	-5.32	-5.80
29	0.20	-5.04	-5.49
30	0.70	-3.64	-3.97
31	0.80	-3.36	-3.66
32	0.80	-3.36	-3.66
33	0.90	-3.08	-3.36
34	1.00	-2.80	-3.05
35	1.00	-2.80	-3.05
36	1.00	-2.80	-3.05
37	1.00	-2.80	-3.05
38	0.70	-3.64	-3.97
39	0.70	-3.64	-3.97
40	0.80	-3.36	-3.66
41	0.80	-3.36	-3.66
42	0.50	-4.20	-4.58
43	0.40	-4.48	-4.88
44	0.20	-5.04	-5.49
45	0.30	-4.76	-5.19
46	0.30	-4.76	-5.19
47	0.40	-4.48	-4.88
48	0.40	-4.48	-4.88
49	0.80	-3.36	-3.66
50	0.90	-3.08	-3.36
Max	1.20	3.36	3.66

Sway

	CURRENT 0.3 ; WAVE	
time (s)	Video	Real Data
0	0.00	-0.84
1	0.00	-0.84
2	-0.50	-2.24
3	-0.30	-1.68
4	-0.10	-1.12
5	-0.10	-1.12
6	-0.20	-1.40
7	-0.20	-1.40
8	-0.30	-1.68
9	0.00	-0.84
10	-0.20	-1.40
11	-0.10	-1.12
12	-0.50	-2.24
13	0.10	-0.56
14	-0.20	-1.40
15	0.00	-0.84
16	-0.30	-1.68
17	-0.10	-1.12
18	0.00	-0.84
19	-0.40	-1.96
20	0.00	-0.84
21	-0.20	-1.40
22	-0.80	-3.08
23	-0.10	-1.12
24	-0.30	-1.68
25	-0.30	-1.68
26	0.00	-0.84
27	-0.20	-1.40
28	-0.40	-1.96
29	-0.20	-1.40
30	-0.50	-2.24
31	-0.50	-2.24
32	-0.50	-2.24
33	-0.20	-1.40
34	-0.70	-2.80
35	0.00	-0.84
36	0.00	-0.84
37	-0.30	-1.68
38	-0.80	-3.08
39	-0.30	-1.68
40	0.00	-0.84
41	-0.20	-1.40
42	-0.10	-1.12
43	0.00	-0.84
44	0.00	-0.84
45	0.00	-0.84
46	-0.30	-1.68
47	-0.40	-1.96
48	-0.10	-1.12
49	-0.40	-1.96
50	-0.50	-2.24
Max	1.00	1.96

Test 2 : Wave Height 7cm No Current; freuency 0.2

Surge

	CURRENT 0 ; WAVE HEIGHT 7cm		
time (s)	Video	Real Data	Read data x Correction factor
0.00	0.00	5.94	6.47
1.00	-5.60	-10.69	-11.65
2.00	-5.30	-9.80	-10.68
3.00	0.00	5.94	6.47
4.00	2.00	11.88	12.95
5.00	-1.90	0.30	0.32
6.00	-6.00	-11.88	-12.95
7.00	-5.50	-10.40	-11.33
8.00	-1.00	2.97	3.24
9.00	-1.80	0.59	0.65
10.00	-1.20	2.38	2.59
11.00	-6.00	-11.88	-12.95
12.00	-3.80	-5.35	-5.83
13.00	1.00	8.91	9.71
14.00	1.50	10.40	11.33
15.00	-2.80	-2.38	-2.59
16.00	-6.10	-12.18	-13.27
17.00	-3.80	-5.35	-5.83
18.00	1.20	9.50	10.36
19.00	1.60	10.69	11.65
20.00	-3.20	-3.56	-3.88
21.00	-6.10	-12.18	-13.27
22.00	-4.00	-5.94	-6.47
23.00	1.10	9.21	10.04
24.00	1.50	10.40	11.33
25.00	-3.20	-3.56	-3.88
26.00	-6.20	-12.47	-13.60
27.00	-3.30	-3.86	-4.21
28.00	0.50	7.43	8.09
29.00	1.90	11.58	12.63
30.00	-2.00	0.00	0.00
31.00	-6.00	-11.88	-12.95
32.00	-4.80	-8.32	-9.06
33.00	0.20	6.53	7.12
34.00	2.00	11.88	12.95
35.00	-1.60	1.19	1.29
36.00	-6.10	-12.18	-13.27
37.00	-4.10	-6.24	-6.80
38.00	0.50	7.43	8.09
39.00	1.50	10.40	11.33
40.00	-3.00	-2.97	-3.24
41.00	-6.10	-12.18	-13.27
42.00	-3.60	-4.75	-5.18
43.00	0.50	7.43	8.09
44.00	0.50	7.43	8.09
45.00	-3.00	-2.97	-3.24
46.00	-6.10	-12.18	-13.27
47.00	-4.10	-6.24	-6.80
48.00	0.30	6.83	7.45
49.00	0.60	7.72	8.42
50.00	-3.30	-3.86	-4.21
Max	8.50	25.25	27.52

Sway

	CURRENT 0 ; WAVE HEIGHT 7cm		
time(s)	Video	Real Data	Read data x Correction factor
0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00
2.00	0.00	0.00	0.00
3.00	0.00	0.00	0.00
4.00	0.00	0.00	0.00
5.00	-0.10	-0.30	-0.32
6.00	0.00	0.00	0.00
7.00	0.10	0.30	0.32
8.00	0.00	0.00	0.00
9.00	0.00	0.00	0.00
10.00	0.00	0.00	0.00
11.00	0.00	0.00	0.00
12.00	0.00	0.00	0.00
13.00	0.00	0.00	0.00
14.00	0.00	0.00	0.00
15.00	-0.10	-0.30	-0.32
16.00	0.00	0.00	0.00
17.00	0.10	0.30	0.32
18.00	0.00	0.00	0.00
19.00	0.00	0.00	0.00
20.00	-0.10	-0.30	-0.32
21.00	0.00	0.00	0.00
22.00	0.00	0.00	0.00
23.00	0.00	0.00	0.00
24.00	-0.10	-0.30	-0.32
25.00	-0.20	-0.59	-0.65
26.00	-0.20	-0.59	-0.65
27.00	0.00	0.00	0.00
28.00	0.00	0.00	0.00
29.00	0.00	0.00	0.00
30.00	-0.10	-0.30	-0.32
31.00	-0.10	-0.30	-0.32
32.00	0.00	0.00	0.00
33.00	0.20	0.59	0.65
34.00	0.00	0.00	0.00
35.00	-0.20	-0.59	-0.65
36.00	-0.10	-0.30	-0.32
37.00	-0.10	-0.30	-0.32
38.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00
40.00	0.00	0.00	0.00
41.00	-0.10	-0.30	-0.32
42.00	0.10	0.30	0.32
43.00	0.00	0.00	0.00
44.00	0.00	0.00	0.00
45.00	0.00	0.00	0.00
46.00	0.00	0.00	0.00
47.00	0.00	0.00	0.00
48.00	0.00	0.00	0.00
49.00	-0.10	-0.30	-0.32
50.00	0.00	0.00	0.00
Max	0.30	0.89	0.97

Test 3: current 0.3 WaveHeight 3cm ; Wave Frequency 0.2

Surge

	CURRENT 0.3 ; WAVE HEIGHT 3cm		
time (s)	Video	Real Data	Real Data x Correction Factor
0	0.00	-3.64	-3.97
1	-1.20	-7.00	-7.63
2	-1.50	-7.84	-8.55
3	-1.50	-7.84	-8.55
4	0.70	-1.68	-1.83
5	-0.10	-3.92	-4.27
6	-1.50	-7.84	-8.55
7	-1.50	-7.84	-8.55
8	0.00	-3.64	-3.97
9	0.80	-1.40	-1.53
10	0.40	-2.52	-2.75
11	-0.90	-6.16	-6.71
12	-1.10	-6.72	-7.32
13	0.20	-3.08	-3.36
14	1.30	0.00	0.00
15	0.40	-2.52	-2.75
16	-0.70	-5.60	-6.10
17	-1.40	-7.56	-8.24
18	-0.40	-4.76	-5.19
19	0.60	-1.96	-2.14
20	0.30	-2.80	-3.05
21	-0.80	-5.88	-6.41
22	-1.70	-8.40	-9.16
23	-0.90	-6.16	-6.71
24	0.40	-2.52	-2.75
25	0.20	-3.08	-3.36
26	-1.40	-7.56	-8.24
27	-1.80	-8.68	-9.46
28	-0.60	-5.32	-5.80
29	0.70	-1.68	-1.83
30	0.20	-3.08	-3.36
31	-1.00	-6.44	-7.02
32	-1.50	-7.84	-8.55
33	-1.50	-7.84	-8.55
34	1.10	-0.56	-0.61
35	0.00	-3.64	-3.97
36	-1.30	-7.28	-7.94
37	-1.50	-7.84	-8.55
38	-0.50	-5.04	-5.49
39	0.80	-1.40	-1.53
40	0.00	-3.64	-3.97
41	-1.40	-7.56	-8.24
42	-1.60	-8.12	-8.85
43	-0.60	-5.32	-5.80
44	0.70	-1.68	-1.83
45	-0.10	-3.92	-4.27
46	-1.60	-8.12	-8.85
47	-1.70	-8.40	-9.16
48	-0.40	-4.76	-5.19
49	0.90	-1.12	-1.22
50	0.50	-2.24	-2.44
Max	1.30	9.24	10.07

Sway

	CURRENT 0.3 ; WAVE HEIGHT 3cm		
time (s)	Video	Real Data	Real Data x Correction Factor
0	0.00	0.00	0.00
1	-0.50	-1.40	-1.53
2	-0.20	-0.56	-0.61
3	0.00	0.00	0.00
4	-0.60	-1.68	-1.83
5	-0.10	-0.28	-0.31
6	-0.30	-0.84	-0.92
7	-0.70	-1.96	-2.14
8	0.00	0.00	0.00
9	-0.50	-1.40	-1.53
10	-0.30	-0.84	-0.92
11	-0.70	-1.96	-2.14
12	-0.50	-1.40	-1.53
13	-0.70	-1.96	-2.14
14	-0.80	-2.24	-2.44
15	0.00	0.00	0.00
16	-0.60	-1.68	-1.83
17	-0.30	-0.84	-0.92
18	-0.10	-0.28	-0.31
19	-0.30	-0.84	-0.92
20	0.00	0.00	0.00
21	0.20	0.56	0.61
22	-0.30	-0.84	-0.92
23	-0.10	-0.28	-0.31
24	0.00	0.00	0.00
25	-0.20	-0.56	-0.61
26	-0.20	-0.56	-0.61
27	-0.10	-0.28	-0.31
28	0.00	0.00	0.00
29	0.00	0.00	0.00
30	-0.20	-0.56	-0.61
31	0.00	0.00	0.00
32	-0.40	-1.12	-1.22
33	-0.40	-1.12	-1.22
34	0.30	0.84	0.92
35	0.10	0.28	0.31
36	-0.10	-0.28	-0.31
37	0.00	0.00	0.00
38	0.20	0.56	0.61
39	-0.60	-1.68	-1.83
40	-0.20	-0.56	-0.61
41	0.20	0.56	0.61
42	0.00	0.00	0.00
43	-0.30	-0.84	-0.92
44	0.00	0.00	0.00
45	-0.10	-0.28	-0.31
46	-0.10	-0.28	-0.31
47	0.10	0.28	0.31
48	-0.30	-0.84	-0.92
49	-0.60	-1.68	-1.83
50	0.10	0.28	0.31
Max	1.20	3.36	3.66

Test 4: Current 0.3Wave Height 7cm;Wave Frequency 0.2 - results are in cm

Surge

	CURRENT 0.3 ; WAVE HEIGHT 7cm		
time (s)	video	real data	real data xcorrection factor
0	0.00	-7.56	-8.24
1	-2.20	-13.72	-14.95
2	-2.00	-13.16	-14.34
3	1.00	-4.76	-5.19
4	2.90	0.56	0.61
5	0.10	-7.28	-7.94
6	-2.10	-13.44	-14.65
7	-2.70	-15.12	-16.48
8	2.00	-1.96	-2.14
9	2.60	-0.28	-0.31
10	-2.00	-13.16	-14.34
11	-2.30	-14.00	-15.26
12	-1.10	-10.64	-11.60
13	3.00	0.84	0.92
14	3.20	1.40	1.53
15	0.00	-7.56	-8.24
16	-2.30	-14.00	-15.26
17	-0.90	-10.08	-10.99
18	2.90	0.56	0.61
19	3.80	3.08	3.36
20	0.60	-5.88	-6.41
21	-1.80	-12.60	-13.73
22	-1.10	-10.64	-11.60
23	2.30	-1.12	-1.22
24	3.80	3.08	3.36
25	1.00	-4.76	-5.19
26	-1.90	-12.88	-14.04
27	-1.80	-12.60	-13.73
28	1.80	-2.52	-2.75
29	3.80	3.08	3.36
30	0.80	-5.32	-5.80
31	-1.90	-12.88	-14.04
32	-1.40	-11.48	-12.51
33	1.80	-2.52	-2.75
34	3.70	2.80	3.05
35	0.50	-6.16	-6.71
36	-1.90	-12.88	-14.04
37	-1.50	-11.76	-12.82
38	1.90	-2.24	-2.44
39	3.10	1.12	1.22
40	-0.20	-8.12	-8.85
41	-2.20	-13.72	-14.95
42	-1.80	-12.60	-13.73
43	1.80	-2.52	-2.75
44	3.40	1.96	2.14
45	0.40	-6.44	-7.02
46	-2.40	-14.28	-15.57
47	-2.00	-13.16	-14.34
48	2.80	0.28	0.31
49	3.20	1.40	1.53
50	-0.10	-7.84	-8.55
Max	6.80	19.04	20.75

Sway

	CURRENT 0.3 ; WAVE HEIGHT 7cm		
time (s)	video	real data	real data xcorrection factor
0	0.00	0.00	0.00
1	0.00	0.00	0.00
2	0.10	0.28	0.31
3	-0.20	-0.56	-0.61
4	-0.20	-0.56	-0.61
5	0.30	0.84	0.92
6	0.20	0.56	0.61
7	-0.30	-0.84	-0.92
8	0.00	0.00	0.00
9	0.10	0.28	0.31
10	0.20	0.56	0.61
11	0.60	1.68	1.83
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	-0.20	-0.56	-0.61
15	-0.30	-0.84	-0.92
16	0.30	0.84	0.92
17	0.30	0.84	0.92
18	-0.40	-1.12	-1.22
19	0.00	0.00	0.00
20	0.30	0.84	0.92
21	0.30	0.84	0.92
22	-0.60	-1.68	-1.83
23	-0.10	-0.28	-0.31
24	0.20	0.56	0.61
25	-0.10	-0.28	-0.31
26	0.10	0.28	0.31
27	0.00	0.00	0.00
28	0.00	0.00	0.00
29	0.00	0.00	0.00
30	-0.20	-0.56	-0.61
31	0.20	0.56	0.61
32	-0.10	-0.28	-0.31
33	0.00	0.00	0.00
34	-0.20	-0.56	-0.61
35	-0.30	-0.84	-0.92
36	0.10	0.28	0.31
37	-0.30	-0.84	-0.92
38	-0.20	-0.56	-0.61
39	0.20	0.56	0.61
40	0.00	0.00	0.00
41	0.50	1.40	1.53
42	0.20	0.56	0.61
43	-0.30	-0.84	-0.92
44	-0.80	-2.24	-2.44
45	0.10	0.28	0.31
46	0.00	0.00	0.00
47	-0.60	-1.68	-1.83
48	-0.40	-1.12	-1.22
49	0.00	0.00	0.00
50	0.20	0.56	0.61
Max	1.40	3.92	4.27

Test 5: Wave 3cm No current; Wave Frequency 0.2 - Results are in cm

Surge

CURRENT 0 ; WAVE HEIGHT 3cm			
time (s)	Video	Real Data	Real Data x Correction Factor
0	0.20	0.57	0.62
1	0.70	1.99	2.17
2	0.90	2.56	2.79
3	0.30	0.85	0.93
4	-0.40	-1.14	-1.24
5	0.20	0.57	0.62
6	0.80	2.27	2.48
7	1.00	2.84	3.10
8	0.30	0.85	0.93
9	-0.50	-1.42	-1.55
10	0.10	0.28	0.31
11	0.80	2.27	2.48
12	0.90	2.56	2.79
13	0.40	1.14	1.24
14	-0.50	-1.42	-1.55
15	0.00	0.00	0.00
16	0.70	1.99	2.17
17	1.00	2.84	3.10
18	0.80	2.27	2.48
19	-0.40	-1.14	-1.24
20	0.40	1.14	1.24
21	0.90	2.56	2.79
22	1.00	2.84	3.10
23	0.10	0.28	0.31
24	-0.40	-1.14	-1.24
25	0.40	1.14	1.24
26	0.90	2.56	2.79
27	0.90	2.56	2.79
28	0.10	0.28	0.31
29	-0.30	-0.85	-0.93
30	0.60	1.70	1.86
31	0.90	2.56	2.79
32	0.90	2.56	2.79
33	0.40	1.14	1.24
34	-0.40	-1.14	-1.24
35	0.30	0.85	0.93
36	0.90	2.56	2.79
37	1.00	2.84	3.10
38	0.70	1.99	2.17
39	-0.40	-1.14	-1.24
40	0.50	1.42	1.55
41	1.10	3.12	3.41
42	1.10	3.12	3.41
43	0.40	1.14	1.24
44	-0.30	-0.85	-0.93
45	0.50	1.42	1.55
46	1.10	3.12	3.41
47	1.30	3.41	3.71
48	0.70	1.99	2.17
49	-0.30	-0.85	-0.93
50	0.40	1.14	1.24
Max	1.80	5.11	5.57

Sway

	CURRENT 0 ; WAVE HEIGHT 3cm		
time (s)	Video	Real Data	Real Data xCorrection Factor
0	0.30	0.85	0.93
1	0.30	0.85	0.93
2	0.30	0.85	0.93
3	-0.30	-0.85	-0.93
4	-0.30	-0.85	-0.93
5	-0.48	-1.36	-1.49
6	-0.66	-1.87	-2.04
7	-0.84	-2.39	-2.60
8	-1.02	-2.90	-3.16
9	-1.20	-3.41	-3.71
10	-1.38	-3.92	-4.27
11	0.25	0.71	0.77
12	0.25	0.71	0.77
13	0.25	0.71	0.77
14	0.30	0.85	0.93
15	0.30	0.85	0.93
16	0.25	0.71	0.77
17	0.25	0.71	0.77
18	0.25	0.71	0.77
19	0.25	0.71	0.77
20	0.25	0.71	0.77
21	0.25	0.71	0.77
22	0.25	0.71	0.77
23	0.25	0.71	0.77
24	0.25	0.71	0.77
25	0.25	0.71	0.77
26	0.25	0.71	0.77
27	0.25	0.71	0.77
28	0.25	0.71	0.77
29	0.25	0.71	0.77
30	0.25	0.71	0.77
31	0.25	0.71	0.77
32	0.20	0.57	0.62
33	0.25	0.71	0.77
34	0.25	0.71	0.77
35	0.25	0.71	0.77
36	0.30	0.85	0.93
37	0.30	0.85	0.93
38	0.30	0.85	0.93
39	0.25	0.71	0.77
40	0.25	0.71	0.77
41	0.30	0.85	0.93
42	0.30	0.85	0.93
43	0.40	1.14	1.24
44	0.34	0.95	1.04
45	0.30	0.85	0.93
46	0.30	0.85	0.93
47	0.35	0.99	1.08
48	0.30	0.85	0.93
49	0.30	0.85	0.93
50	0.30	0.85	0.93
Max	0.20	0.57	0.62

Water Fluctuation

time (s)	height (cm)
0	1
1	-1.5
2	-2
3	-1.5
4	0
5	0.2
6	-1.1
7	-2
8	-1
9	0
10	0.3
11	-1
12	-2.2
13	-1
14	0.5
15	-0.5
16	-2
17	-2
18	-0.5
19	0.5
20	-0.2
21	-1.8
22	-2
23	-1
24	0.5
25	0
26	-2
27	-2.5
28	-0.5
29	0.5
30	0
31	-1.5
32	-2
33	-0.8
34	0.5
35	0
36	-1.5
37	-2
38	-0.5
39	0.5
40	0
41	-1
42	-2.2
43	-2
44	-0.2
45	0.5
46	-1
47	-2
48	-0.5
49	0.5
50	0

Test 6: Current 0.2 No Wave - Results are in cm

Surge

CURRENT 0.2 ; WAVE HEIGHT 0			
time (s)	Video	Real Data	Real Data x Correction Factor
0	-0.70	-1.99	-2.17
1	-0.70	-1.99	-2.17
2	-0.70	-1.99	-2.17
3	-0.70	-1.99	-2.17
4	-0.60	-1.70	-1.86
5	-0.60	-1.70	-1.86
6	-0.70	-1.99	-2.17
7	-0.90	-2.56	-2.79
8	-0.70	-1.99	-2.17
9	-0.80	-2.27	-2.48
10	-0.80	-2.27	-2.48
11	-1.00	-2.84	-3.10
12	-1.00	-2.84	-3.10
13	-1.10	-3.12	-3.41
14	-1.10	-3.12	-3.41
15	-1.20	-3.41	-3.71
16	-1.20	-3.41	-3.71
17	-1.20	-3.41	-3.71
18	-1.20	-3.41	-3.71
19	-1.20	-3.41	-3.71
20	-1.10	-3.12	-3.41
21	-1.10	-3.12	-3.41
22	-1.00	-2.84	-3.10
23	-1.00	-2.84	-3.10
24	-0.90	-2.56	-2.79
25	-0.80	-2.27	-2.48
26	-0.80	-2.27	-2.48
27	-0.80	-2.27	-2.48
28	-0.80	-2.27	-2.48
29	-0.80	-2.27	-2.48
30	-0.80	-2.27	-2.48
31	-0.90	-2.56	-2.79
32	-0.80	-2.27	-2.48
33	-0.90	-2.56	-2.79
34	-0.90	-2.56	-2.79
35	-1.00	-2.84	-3.10
36	-0.90	-2.56	-2.79
37	-0.90	-2.56	-2.79
38	-1.00	-2.84	-3.10
39	-1.00	-2.84	-3.10
40	-1.00	-2.84	-3.10
41	-0.80	-2.27	-2.48
42	-1.00	-2.84	-3.10
43	-0.80	-2.27	-2.48
44	-0.90	-2.56	-2.79
45	-0.80	-2.27	-2.48
46	-0.80	-2.27	-2.48
47	-0.80	-2.27	-2.48
48	-0.70	-1.99	-2.17
49	-0.80	-2.27	-2.48
50	-0.70	-1.99	-2.17
Max	0.70	1.99	2.17

Sway

CURRENT 0.2 ; WAVE HEIGHT 0			
time (s)	Video	Real Data	Real Data xCorrection Factor
0	0.00	0.00	0.00
1	0.10	0.28	0.31
2	0.20	0.57	0.62
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.20	0.57	0.62
8	0.10	0.28	0.31
9	0.20	0.57	0.62
10	0.20	0.57	0.62
11	0.20	0.57	0.62
12	0.20	0.57	0.62
13	0.20	0.57	0.62
14	0.20	0.57	0.62
15	0.20	0.57	0.62
16	0.20	0.57	0.62
17	0.20	0.57	0.62
18	0.20	0.57	0.62
19	0.20	0.57	0.62
20	0.20	0.57	0.62
21	0.10	0.28	0.31
22	0.20	0.57	0.62
23	0.20	0.57	0.62
24	0.10	0.28	0.31
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.10	0.28	0.31
28	0.20	0.57	0.62
29	0.20	0.57	0.62
30	0.10	0.28	0.31
31	0.10	0.28	0.31
32	0.10	0.28	0.31
33	0.20	0.57	0.62
34	0.10	0.28	0.31
35	0.10	0.28	0.31
36	0.10	0.28	0.31
37	0.10	0.28	0.31
38	0.10	0.28	0.31
39	0.10	0.28	0.31
40	0.10	0.28	0.31
41	0.00	0.00	0.00
42	0.10	0.28	0.31
43	0.00	0.00	0.00
44	0.10	0.28	0.31
45	0.10	0.28	0.31
46	0.10	0.28	0.31
47	0.10	0.28	0.31
48	0.10	0.28	0.31
49	0.20	0.57	0.62
50	0.30	0.85	0.93
Max	0.30	0.85	0.93

Water Fluctuation

time (s)	height(cm)
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
32	0
33	0
34	0
35	0
36	0
37	0
38	0
39	0
40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	0
50	0

Test 7: Current 0.2 Waveheight 3cm; Wave Frequency 0.2 - Results are in cm

Surge

RRENT 0.2 ; WAVE HEIGHT 3cm			
time (s)	Video	Real Data	Real Data x Correction Factor
0	-1.60	-4.54	-4.95
1	-0.80	-2.27	-2.48
2	-0.80	-2.27	-2.48
3	-1.40	-3.98	-4.33
4	-1.60	-4.54	-4.95
5	-1.00	-2.84	-3.10
6	-0.80	-2.27	-2.48
7	-0.80	-2.27	-2.48
8	-1.30	-3.69	-4.02
9	-1.60	-4.54	-4.95
10	-1.50	-4.26	-4.64
11	-0.10	-0.28	-0.31
12	-0.90	-2.56	-2.79
13	-1.60	-4.54	-4.95
14	-2.00	-5.68	-6.19
15	-1.20	-3.41	-3.71
16	-1.30	-3.69	-4.02
17	-0.80	-2.27	-2.48
18	-1.30	-3.69	-4.02
19	-1.80	-5.11	-5.57
20	-1.80	-5.11	-5.57
21	-1.10	-3.12	-3.41
22	-0.80	-2.27	-2.48
23	-1.40	-3.98	-4.33
24	-1.60	-4.54	-4.95
25	-1.10	-3.12	-3.41
26	-0.90	-2.56	-2.79
27	-0.80	-2.27	-2.48
28	-1.30	-3.69	-4.02
29	-1.60	-4.54	-4.95
30	-1.40	-3.98	-4.33
31	-0.90	-2.56	-2.79
32	-0.60	-1.70	-1.86
33	-1.10	-3.12	-3.41
34	-1.50	-4.26	-4.64
35	-1.20	-3.41	-3.71
36	-0.80	-2.27	-2.48
37	-0.70	-1.99	-2.17
38	-1.40	-3.98	-4.33
39	-0.70	-1.99	-2.17
40	-1.40	-3.98	-4.33
41	-0.80	-2.27	-2.48
42	-0.90	-2.56	-2.79
43	-1.30	-3.69	-4.02
44	-1.70	-4.83	-5.26
45	-1.60	-4.54	-4.95
46	-0.80	-2.27	-2.48
47	-0.70	-1.99	-2.17
48	-1.50	-4.26	-4.64
49	-1.70	-4.83	-5.26
50	-1.50	-4.26	-4.64
Max	1.30	3.69	4.02

Sway

CURRENT 0.2 ; WAVE HEIGHT 3cm			
time (s)	Video	Real Data	Real Data xCorrection Factor
0	0.30	0.85	0.93
1	0.30	0.85	0.93
2	0.20	0.57	0.62
3	0.40	1.14	1.24
4	0.30	0.85	0.93
5	0.20	0.57	0.62
6	0.30	0.85	0.93
7	0.30	0.85	0.93
8	0.30	0.85	0.93
9	0.30	0.85	0.93
10	0.30	0.85	0.93
11	0.40	1.14	1.24
12	0.40	1.14	1.24
13	0.40	1.14	1.24
14	0.40	1.14	1.24
15	0.40	1.14	1.24
16	0.40	1.14	1.24
17	0.40	1.14	1.24
18	0.40	1.14	1.24
19	0.40	1.14	1.24
20	0.40	1.14	1.24
21	0.30	0.85	0.93
22	0.30	0.85	0.93
23	0.30	0.85	0.93
24	0.30	0.85	0.93
25	0.30	0.85	0.93
26	0.30	0.85	0.93
27	0.30	0.85	0.93
28	0.30	0.85	0.93
29	0.40	1.14	1.24
30	0.30	0.85	0.93
31	0.30	0.85	0.93
32	0.40	1.14	1.24
33	0.40	1.14	1.24
34	0.30	0.85	0.93
35	0.30	0.85	0.93
36	0.30	0.85	0.93
37	0.30	0.85	0.93
38	0.30	0.85	0.93
39	0.30	0.85	0.93
40	0.30	0.85	0.93
41	0.30	0.85	0.93
42	0.30	0.85	0.93
43	0.30	0.85	0.93
44	0.30	0.85	0.93
45	0.30	0.85	0.93
46	0.40	1.14	1.24
47	0.40	1.14	1.24
48	0.30	0.85	0.93
49	0.40	1.14	1.24
50	0.40	1.14	1.24
Max	0.40	1.14	1.24

Water Fluctuation

time (s)		height (cm)
0	-2	-1.6
1	-0.5	-0.1
2	0.5	0.9
3	0	0.4
4	-1	-0.6
5	-2	-1.6
6	-1	-0.6
7	0.2	0.6
8	0	0.4
9	-0.5	-0.1
10	-1.5	-1.1
11	-1	-0.6
12	0.5	0.9
13	0	0.4
14	-1	-0.6
15	-1.5	-1.1
16	-1.2	-0.8
17	0	0.4
18	0.5	0.9
19	-1	-0.6
20	-1.5	-1.1
21	-1	-0.6
22	0.5	0.9
23	0.5	0.9
24	-0.8	-0.4
25	-1.5	-1.1
26	-1	-0.6
27	0.3	0.7
28	0.5	0.9
29	-0.3	0.1
30	-1.5	-1.1
31	-1	-0.6
32	0	0.4
33	0.5	0.9
34	0	0.4
35	-1.5	-1.1
36	-1	-0.6
37	0.7	1.1
38	0.5	0.9
39	-1	-0.6
40	-1.5	-1.1
41	-0.5	-0.1
42	0.5	0.9
43	-0.2	0.2
44	-1	-0.6
45	-1.5	-1.1
46	-1	-0.6
47	0.7	1.1
48	0.5	0.9
49	-0.5	-0.1
50	-1.5	-1.1

Test 8: Current 0.2 Wave height 7cm; Wave frequency 0.2 Results are in cm

Surge

CURRENT 0.2 ; WAVE HEIGHT 7cm			
time (s)	Video	Real Data	Real Data x Correction Factor
0	-0.60	-1.70	-1.86
1	0.40	1.14	1.24
2	-1.80	-5.11	-5.57
3	-3.00	-8.52	-9.29
4	-2.00	-5.68	-6.19
5	-0.30	-0.85	-0.93
6	0.40	1.14	1.24
7	-1.50	-4.26	-4.64
8	-3.00	-8.52	-9.29
9	-2.70	-7.67	-8.36
10	-0.60	-1.70	-1.86
11	0.20	0.57	0.62
12	-2.30	-6.53	-7.12
13	-3.10	-8.80	-9.60
14	-2.30	-6.53	-7.12
15	-0.50	-1.42	-1.55
16	0.00	0.00	0.00
17	-2.20	-6.25	-6.81
18	-3.10	-8.80	-9.60
19	-2.30	-6.53	-7.12
20	-0.30	-0.85	-0.93
21	0.00	0.00	0.00
22	-2.50	-7.10	-7.74
23	-3.40	-9.66	-10.53
24	-2.70	-7.67	-8.36
25	-0.60	-1.70	-1.86
26	0.10	0.28	0.31
27	-0.23	-0.65	-0.71
28	-3.20	-9.09	-9.91
29	-3.00	-8.52	-9.29
30	-0.90	-2.56	-2.79
31	0.50	1.42	1.55
32	-2.30	-6.53	-7.12
33	-3.00	-8.52	-9.29
34	-2.60	-7.38	-8.05
35	-0.30	-0.85	-0.93
36	-0.30	-0.85	-0.93
37	-2.90	-8.24	-8.98
38	-3.50	-9.94	-10.83
39	-2.80	-7.95	-8.67
40	-1.00	-2.84	-3.10
41	0.10	0.28	0.31
42	-2.10	-5.96	-6.50
43	-3.00	-8.52	-9.29
44	-1.80	-5.11	-5.57
45	0.50	1.42	1.55
46	-1.10	-3.12	-3.41
47	-3.10	-8.80	-9.60
48	-3.20	-9.09	-9.91
49	-1.90	-5.40	-5.88
50	0.00	0.00	0.00
Max	3.70	10.51	11.45

Sway

CURRENT 0.2 ; WAVE HEIGHT 7cm			
time (s)	Video	Real Data	Real Data xCorrection Factor
0	0.20	0.57	0.62
1	0.20	0.57	0.62
2	0.30	0.85	0.93
3	0.50	1.42	1.55
4	0.30	0.85	0.93
5	0.30	0.85	0.93
6	0.20	0.57	0.62
7	0.30	0.85	0.93
8	0.50	1.42	1.55
9	0.50	1.42	1.55
10	0.30	0.85	0.93
11	0.20	0.57	0.62
12	0.10	0.28	0.31
13	0.60	1.70	1.86
14	0.30	0.85	0.93
15	0.10	0.28	0.31
16	0.10	0.28	0.31
17	0.40	1.14	1.24
18	0.40	1.14	1.24
19	0.40	1.14	1.24
20	0.40	1.14	1.24
21	0.10	0.28	0.31
22	0.40	1.14	1.24
23	0.60	1.70	1.86
24	0.30	0.85	0.93
25	0.30	0.85	0.93
26	0.30	0.85	0.93
27	0.40	1.14	1.24
28	0.60	1.70	1.86
29	0.60	1.70	1.86
30	0.30	0.85	0.93
31	0.20	0.57	0.62
32	0.40	1.14	1.24
33	0.70	1.99	2.17
34	0.40	1.14	1.24
35	0.10	0.28	0.31
36	0.20	0.57	0.62
37	0.50	1.42	1.55
38	0.60	1.70	1.86
39	0.40	1.14	1.24
40	0.40	1.14	1.24
41	0.30	0.85	0.93
42	0.30	0.85	0.93
43	0.70	1.99	2.17
44	0.40	1.14	1.24
45	0.10	0.28	0.31
46	0.40	1.14	1.24
47	0.70	1.99	2.17
48	0.60	1.70	1.86
49	0.60	1.70	1.86
50	0.20	0.57	0.62
Max	0.60	1.70	1.86

Water Fluctuation

time (s)	Video (cm)	Real Height (cm)
0	-0.8	-2.05
1	1	2.56
2	1.2	3.07
3	-0.8	-2.05
4	-1.5	-3.84
5	-0.9	-2.30
6	1.1	2.82
7	-0.1	-0.26
8	-1	-2.56
9	-1.5	-3.84
10	-0.5	-1.28
11	1	2.56
12	0.8	2.05
13	-0.7	-1.79
14	-1.5	-3.84
15	-0.3	-0.77
16	1.2	3.07
17	1	2.56
18	-0.3	-0.77
19	-1.5	-3.84
20	-0.4	-1.02
21	1.1	2.82
22	1	2.56
23	-1.2	-3.07
24	-1.3	-3.33
25	-0.5	-1.28
26	1.2	3.07
27	0.9	2.30
28	-0.9	-2.30
29	-1.4	-3.58
30	-0.7	-1.79
31	1.2	3.07
32	0.9	2.30
33	-1	-2.56
34	-1.5	-3.84
35	-0.2	-0.51
36	1.2	3.07
37	-0.1	-0.26
38	-0.9	-2.30
39	-1.6	-4.10
40	-0.3	-0.77
41	1.2	3.07
42	0.6	1.54
43	-1	-2.56
44	-1.4	-3.58
45	-0.3	-0.77
46	1.3	3.33
47	1	2.56
48	-0.6	-1.54
49	-1.6	-4.10
50	-0.6	-1.54

Appendix 2.0 Table 2.2 - Model to Prototype Multiplier for the Variables Commonly Used in Mechanics under Froude Scaling" (Chakrabarti, Offshore Stucture Modelling, 1994).

TABLE 2.2
MODEL TO PROTOTYPE MULTIPLIER FOR THE VARIABLES COMMONLY USED IN MECHANICS UNDER FROUDE SCALING

VARIABLE	UNIT	SCALE FACTOR	REMARKS
GEOMETRY			
Length	L	λ	Any characteristic dimension of the object
Area	L^2	λ^2	Surface area or projected area on a plane
Volume	L^3	λ^3	For any portion of the object
Angle	None	1	e.g., between members or solid angle
Radius of Gyration	L	λ	Measured from a fixed point
Moment of Inertia Area	L^4	λ^4	
Moment of Inertia Mass	ML^2	λ^5	Taken about a fixed point
Center of Gravity	L	λ	Measured from a reference point
KINEMATICS & DYNAMICS			
Time	T	$\lambda^{1/2}$	Same reference point (e.g., starting time) is considered as zero time
Acceleration	LT^{-2}	1	Rate of change of velocity
Velocity	LT^{-1}	$\lambda^{1/2}$	Rate of change of displacement

TABLE 2.2 CONTD.

VARIABLE	UNIT	SCALE FACTOR	REMARKS
Displacement	L	λ	Position at rest is considered as zero
Angular Acceleration	T^{-2}	λ^{-1}	Rate of change of angular velocity
Angular Velocity	T^{-1}	$\lambda^{1/2}$	Rate of change of angular displacement
Angular Displacement	None	1	Zero degree is taken as reference
Spring Constant (Linear)	MT^{-2}	λ^2	Force per unit length of extension
Damping Coefficient	MT^{-1}	$\lambda^{5/2}$	Resistance (viscous) against oscillation
Damping Factor	None	1	Ratio of damping and critical damping coefficient
Natural Period	T	$\lambda^{1/2}$	Period at which inertia force = restoring force
Momentum	MLT^{-1}	$\lambda^{7/2}$	Mass times linear velocity
Angular Momentum	ML^2T^{-1}	$\lambda^{9/2}$	Mass moment of inertia times angular velocity
Torque	ML^2T^{-2}	λ^4	Tangential force times distance
Work	ML^2T^{-2}	λ^4	Force applied times distance moved
Power	ML^2T^{-3}	$\lambda^{7/2}$	Rate of work

TABLE 2.2 CONTD.

VARIABLE	UNIT	SCALE FACTOR	REMARKS
Impulse	MLT^{-1}	$\lambda^{7/2}$	Constant force times its short duration of time
Force, Thrust, Resistance	MLT^{-2}	λ^3	Action of one body on another to change or tend to change the state of motion of the body acted on
STATICS			
Stiffness	ML^3T^{-2}	λ^5	Modulus of elasticity times the moment of inertia, EI
Stress	$ML^{-1}T^{-2}$	λ	Force on an element per unit area
Moment	ML^2T^{-2}	λ^4	Applied force times its distance from a fixed point
Shear	MLT^{-2}	λ^3	Force per unit cross sectional area parallel to the force
Section Modulus	L^3	λ^3	Area moment of inertia divided by the distance from the neutral axis to the extreme fiber
HYDRAULICS			
Kinetic Energy	ML^2T^{-2}	λ^4	Capacity of a body for doing work due to its configuration
Pressure Energy	ML^2T^{-2}	λ^4	Energy due to pressure head
Potential Energy	ML^2T^{-2}	λ^4	Capacity of a body for doing work due to its configuration
Friction Loss	ML^2T^{-2}	λ^4	Loss of energy or work due to friction

TABLE 2.2 CONTD.

VARIABLE	UNIT	SCALE FACTOR	REMARKS
SCOUR			
Particle Diameter	L	λ	For same prototype material
Free Settling Velocity	LT^{-1}	$\sqrt{\lambda}$	Final velocity of a freely falling particle in a medium
Sediment Number	None	1	Nondimensional no. based on velocity and particle size
Shield's Number	None	1	Nondimensional no. based on velocity and particle size
WAVE MECHANICS			
Wave Height	L	λ	Consecutive crest to trough distance
Wave Period	T	$\sqrt{\lambda}$	Time between two successive crests passing a point
Wave Length	L	λ	Distance between two successive crests at a given time
Celerity	LT^{-1}	$\sqrt{\lambda}$	Velocity of wave (crest, for example)
Particle Velocity	LT^{-1}	$\sqrt{\lambda}$	Rate of change of movement of a water particle
Particle Acceleration	LT^{-2}	1	Rate of change of velocity of a water particle
Particle Orbits	L	λ	Path of a water particle (closed or open)

TABLE 2.2 CONTD.

VARIABLE	UNIT	SCALE FACTOR	REMARKS
Wave Elevation	L	λ	Form of wave (distance from still waterline)
Wave Pressure	$ML^{-1}T^{-2}$	λ	Force exerted by a water particle per unit area
Keulegan-Carpenter Parameter	None	1	Dependence of hydrodynamic coefficients on this parameter
<u>STABILITY</u>			
Displacement (Volume)	L^3	λ^3	Volume of water moved by a submerged object (or part thereof)
Righting & Overturning Moment (Hard Volume)	ML^2T^{-2}	λ^4	Moment about a fixed point of a displaced weight and dead weight, respectively
Natural Period	T	$\sqrt{\lambda}$	Period of free oscillation in still water due to an initial disturbance
Metacenter	L	λ	Instantaneous center of rotation
Center of Buoyancy	L	λ	Distance of C.G. of displaced volume from a fixed point
Soft Volume	L^3	λ^3	Volume of trapped air in a member
Buoyancy Pickup per Unit Angle	L^3	λ^3	Increase in displaced volume per unit tilt angle

TABLE 2.2 CONTD.

VARIABLE	UNIT	SCALE FACTOR	REMARKS
<u>MATERIAL PROPERTIES</u>			
Density	ML^{-3}	1	Mass per unit volume
Modulus of Elasticity	$ML^{-1}T^{-2}$	λ	Ratio of tensile or compressive stress to strain
Modulus of Rigidity	$ML^{-1}T^{-2}$	λ	Ratio of shearing stress to strain

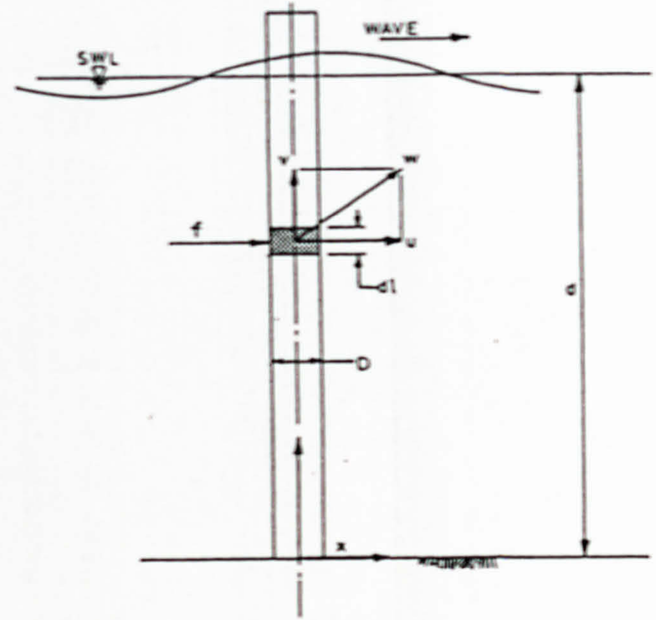

FIGURE 2.1
DEFINITION SKETCH OF WAVE FORCE ON SMALL CYLINDER

$$f = \rho C_M \frac{\pi}{4} D^2 \dot{u} + \frac{1}{2} \rho C_D D |u| u \qquad (2.32)$$

Appendix 3.0 "Development of the Prince Field"

OTC 14173

Development of the Prince Field

J.R. Koon, MODEC International LLC, Bart Heijermans, El Paso Energy Partners, L.P, P.G. Wybro, SEA Engineering, Inc.

Abstract

This paper covers the development of the Prince (formerly known as Sunday Silence) Field. The paper outlines how the lease operator and owners in conjunction with turnkey contractors succeeded in developing a relatively small oil field (in deepwater terms) in an environment of low oil prices. This work included the first application of the "MOSES" Tension Leg Platform. The "MOSES" TLP is the first of a new 4th generation in TLP designs that introduces a new hull configuration offering the industry improved platform motions, lower cost, and less fabrication time than other deepwater platform concepts. The successful completion of the development of the Prince Field proves that the industry can execute innovative deepwater development projects on a lump sum contract basis in record setting time frames without costly overruns.

Introduction

The Prince Field is an oil discovery with associated gas located in Ewing Bank Block 958, 959, and 1003, 80 miles offshore Louisiana in a water depth of 1490 ft. (Reference Figure 1) The three leases are unitized in the Ewing Bank Block 1003 Unit. The Prince Field was developed by means of four (4) predrilled wells that were completed and tied back via top tensioned risers to dry trees located on a MOSES TLP. Oil and associated gas are processed to pipeline specifications on the platform and exported via two (2) export steel catenary risers (SCR). The pipelines and SCR's were pre-laid in April 2001, and the TLP was installed in July 2001. The first riser was installed and the initial well was brought on-stream in September 2001.

The development of the Prince Field can be characterized by the following industry trendsetting activities:

- The Prince Field was the first deepwater field that received royalty relief under the Deepwater Royalty Relief Outer Continental Royalty Relief Act.
- A MOSES TLP was selected for the Prince Field development after four competitive bids had been reviewed. This marked the first time in the Gulf of Mexico that competitive bidding was used for a turnkey deepwater floating platform concept selection and the first time that the MOSES TLP was selected.
- The SCR's designed for the Prince Field development are the world's shallowest SCRs suspended from a floating platform. Additional details are provided in the paper listed in the reference section [1].
- The Prince Field development marks the first time that the working interest owner in the leases (El Paso Production GOM, Inc.) decided to contract with a pipeline and platform infrastructure company (El Paso Energy Partners, L.P.) to have El Paso Energy Partners own and operate the deepwater platform and process production from the field for a fee. This arrangement lowered the development costs and made it possible for El Paso Production GOM, Inc. to develop the field with a deepwater platform in lieu of a subsea tie-back.
- The TLP hull is the first use of a new 4th generation TLP design that offers the industry a new alternative with dry tree or wet tree capability.
- The TLP was designed so that it could be relocated into 6000-ft. water depth.

This paper discusses the unique field history, development options that were considered for the Prince Field, and the basis for the decision to use a MOSES TLP, in the context of the field development philosophy and main project drivers. The paper describes the innovative business arrangement between two companies, El Paso Energy Partners and El Paso Production GOM, which is a subsidiary of El Paso Corporation, in order to achieve a full-scale development of a relatively small deepwater oil field. The paper provides an overview of the development of the MOSES TLP from the pre-project stage through detail design, construction and installation of the platform, pipelines and risers. The paper highlights the lessons learned from both the operator's and the contractor's viewpoint in the application of the first MOSES TLP.

Field History

Tatham Offshore Development, Inc. ("TODI") discovered the Sunday Silence Field (later to become the Prince Field) in July 1994 when it encountered approximately 380 feet of oil and gas pay. A second appraisal well was drilled immediately after the discovery well; the well was tested at sustained rates of approximately 8,700 barrels of oil per day and 5.4 million cubic feet of gas per day. Several development studies were initiated by TODI in 1994 following the discovery and initial appraisal well of the Prince Field. TODI lacked the financial resources to develop the field on their own and tried to attract the interest of other E&P companies to partner in the field development. In August of 1998, a subsidiary of El Paso Corporation acquired the field from TODI as part of a related transaction to acquire TODI's parent company and Leviathan Gas Pipeline Partners, L.P. General Partner. In October 1998 through a series of transactions, Leviathan Gas Pipeline Partners, L.P. (Leviathan changed its name to El Paso Energy Partners, L.P. in 2000) through its wholly-owned subsidiary Flextrend Development Company L.L.C., purchased a 100% working interest with the objective to use this field as a catalyst to start its deepwater platform business. At the same time El Paso Energy Partners commenced the efforts of selling down its interest in the field under an arrangement where it would own the platform and the pipelines as an extension of its shelf infrastructure. Late 1998, El Paso Energy Partners successfully drilled a delineation well that encountered 80 ft. of net pay.

This Sunday Silence discovery was the first Gulf of Mexico prospect to file for and to be granted royalty relief under the 1996 Deep Water Royalty Act based on an application that was submitted by TODI in October of 1996. TODI's initial development plan included partial processing on a Spar buoy platform with a multi-phase export pipeline tied back to a host platform located on the outer continental shelf.

With the change in operatorship mentioned above, a change in development concept was critical to the commercial development of the field. El Paso Energy Partners' challenge then was to demonstrate to the MMS that changing the requirements (i) to develop the field with a lowest cost generic floating platform instead of a specific deepwater platform such as the Spar Buoy Platform and (ii) to install a full process facility instead of a partial processing facility, would not constitute a material change that could result in a withdrawal of the royalty abatement. The MMS accepted the changes to the development plan in April of 1999, but reinforced the requirement to commence construction of the hull by September of 1999 with first production targeted for June 2001. The project schedule, which is always a driver in the offshore world, became even more of a critical aspect of the field development since meeting these schedule deadlines were now conditions for the granting of the royalty relief itself and the development of the field under the MMS' suspension of operations (SOP) schedule.

In July 1999, El Paso Energy Partners awarded MODEC International a turnkey contract for the design, fabrication and installation of the MOSES TLP, tendons, and four production risers. Detailed design work on the Prince platform began. Steel was ordered and plans were made to commence fabrication of the hull in mid September as scheduled in the terms of the royalty relief award and SOP schedule. During this time period, as part of its efforts to sell down its interest in the field, El Paso Energy Partners received a favorable farm out offer from Sonat E&P who soon would become part of El Paso Corporation upon the closing the El Paso Corporation and Sonat Inc. merger. Sonat E&P's offer involved a subsea development instead of a full field development using the MOSES TLP. El Paso Energy Partners accepted Sonat E&P's offer, suspended its TLP contract on September 17, 1999 and started pursuing other locations for the TLP. Sonat E&P, now named El Paso Production GOM, renamed the Sunday Silence field the "Prince" field and drilled the fourth well late 1999. The MMS withdrew the royalty relief as the result of the new operator changing the development plan. The fourth well was a success and encountered 200 ft. of net pay.

The success of the fourth well led to El Paso Corporation's decision in late March 2000 to proceed with a full field development using the MOSES TLP. El Paso Energy Partners was successful in negotiating an innovative business arrangement with El Paso Production GOM under which El Paso Energy Partners would construct, own and operate the Prince TLP. El Paso Energy Partners re-activated its contract from its "temporary suspension mode" and the work on the Prince platform began in earnest.

Despite the six-month hiatus in which absolutely no work was done on the TLP concept, the project still needed to meet its original offshore installation window due to the milestone deadlines tied to the SOP schedule. In effect, the first TLP of this design would now have to be designed and built in record time. The Prince project team commenced design in earnest in April 2000 and completed installation July 18, 2001, a very short 15½ months later.

System Selection

When El Paso Energy Partners became the owner and operator of the Prince Field in 1998, it realized that it would face several challenging in the development of the field. The deepwater industry had changed significantly over the two years that had gone by after TODI had submitted its development plan as part of their royalty relief application. At that time, a Spar Buoy Platform was the only feasible alternative that was used for the development of the Neptune field, but by October of 1998, El Paso Energy Partners believed that (i) a mini-TLP, with the choice between the Atlantia marketed SeaStar design and the MODEC marketed MOSES design and (ii) Kvaerner Deep Draft Floater could be used to develop the Prince field in addition to the Spar Buoy Platform. El Paso Energy Partners became convinced that all four concepts were technically feasible and mature and decided to use market forces and requested a bid package from these four companies based on a functional specification. In July 1999 El Paso Energy Partners awarded a turnkey contract for the design, construction and installation of the MOSES

TLP, tendons and the production risers.

Ownership Structure

El Paso Production GOM, the working interest owner in the Prince Field, entered into an agreement with El Paso Energy Partners in March of 2000 under which El Paso Energy Partners would (i) be responsible for the construction and installation of the Prince platform and export pipelines and (ii) own and operate the Prince platform and (iii) be compensated through a combination of demand charges and processing fees. This business arrangement resulted in a significant decrease in the development cost for the lease owner and allowed the lease owner to develop the full potential of the field with a stand-alone platform. El Paso Energy Partners would market incremental capacity for off-lease processing to lease owners in the near vicinity of the Prince platform. This business arrangement started the trend of pipeline companies owning deepwater platforms as portals for their pipeline infrastructure.

Field Development Plan

When in March of 2000 El Paso Energy Partners re-activated its suspended contract with MODEC International, the original field development plan had changed. The new lease owner, El Paso Production GOM, Inc. had filed a deepwater operations plan with the MMS that allowed for production from the four wells that had been drilled in the field. El Paso Energy Partners decided to design the Prince platform for (i) 50,000 barrels of oil per day and 80 million cubic feet of gas per day, (ii) four production risers with dry trees, and (iii) a 1,250 short tonne workover rig. The facilities would be located on three decks with 50,000 square feet of space. El Paso Energy Partners plan was to market unused capacity to owners of leases in the near vicinity of the Prince platform for offlease processing. The oil would be gathered through a new 10 mile 12 inch pipeline to a subsea interconnect with the Poseidon Oil Pipeline in Ewing Bank Block 873 and the gas would be gathered through a new 16 mile 12 inch gas pipeline to an interconnect with the Manta Ray Offshore Gathering System on the South Timmablier Block 292 platform.

Project Execution Plan

El Paso Energy Partners decided in 1999 that it would award a turnkey contract for the hull, mooring system, production risers and platform installation, but that it would manage themselves the design, procurement, fabrication and construction of the topside facilities and the export pipelines. The fabrication of the deck and the assembly of the topside facilities was awarded to Omega Natchiq in May of 2000. El Paso Energy Partners formed a small project team consisting of a project manager, topsides manager, interface coordinator and export pipeline manager that worked closely with MODEC, Omega, the installation contractor Heerema and the export pipelines contractor Allseas in managing this fast track project.

MOSES Development

Dr. Pieter Wybro conceived the initial MOSES concept in 1991. In 1994, MODEC entered into a joint development and marketing agreement with SEA Engineering and AmClyde covering the MOSES design. Concept development work continued in 1995 through 1997 and included a model test at Marin, ABS review of a site-specific design, and initial project team building. The chronology of events that follows indicates the time and effort required to bring new technology to the market place:

1991	MOSES Development Commenced
1992-93	JOIA Field Trials of 1/3 Scale Mini-TLP
1995	Proof-of-Concept Model Test
1996	ABS Review of Concept, Approval in Principle
1997	Change to Flat Plate Construction & Integration of Drilling Rig
1998-99	Design of MOSES Model 503 and 402*
1999	Model Test of MOSES 402
1999	ABS Approval in Principle MOSES Model 402
1999	Sunday Silence Contract Award (MOSES Model 402)
1999	Detail Design of MOSES Model 804
2000	Model Test of MOSES 804
2000	Prince Contract Award (MOSES Model 402)

* Note that the above Model numbers indicate the payload in terms of thousands of tons (payload does not include weight of the deck steel) and water depth rating in terms of thousands of feet. Therefore, MOSES 503 means that the TLP design has a payload capacity of 5,000 tons and a water depth rating of 3,000 feet.

Based on favorable reaction of the industry to the MOSES design, MODEC commenced a concerted and significant effort in late 1997 and early 1998 to advance MOSES to a "project ready" condition. A formal business plan was developed and funded for execution. This initiative included the following:

- Development and implementation of a formal Business Plan.
- Identifying and solving technical gaps in the MOSES design.
- Optimizing and finalizing the hull configuration.
- Developing fabrication and other construction specifications.
- Building a core team dedicated full time to MOSES development. The core team is the nucleus to go forward with executing a project.
- Developing project execution procedures.
- Involving key subcontractors and suppliers into the MOSES development effort.
- Undertaking constructability and installability reviews by shipyards, fabrication yards and installation contractors.

- Developing a base case design for a 5000 s. t. payload in 3000 ft. water depth, i.e., MOSES 503, to a high level of engineering completion.
- Conducting an ABS review of the MOSES 503.
- Model testing of the MOSES 503.
- Completing a substantial portion of the detail engineering.

The objectives of the above initiative were met. A key cornerstone in the success of the initiative was building of the core team:

- The core team was selected to a large extent based on the extent and success of each individual's experience with designing, building, installing and operating TLPs. This team was dedicated full time to the MOSES 503 over a two-year period.
- A key influence in this team building was locating the MOSES Development Team in a separate office away from other business activities. Thus, the efforts of the MOSES Development Team were not diluted by other business activities; the team was free to focus full time on MOSES' final development stage to become "project ready".
- The project team for the Sunday Silence/Prince Development project consisted of the MOSES Development core team supplemented by additional employees and consultants with previous TLP experience. This preserved continuity, commitment, and dedication to the ideas and decisions made in the concept development phase.

Platform Components and Scope

The platform facilities are designed to process 50,000 bopd and 80 mmscfg. The platform is composed of a three level deck capable of carrying a total operating topsides payload of approximately 6100 s. tons. The hull is a 14,437 s. ton displacement unit tethered to the seabed by eight 24" diameter tendons each connecting directly into a 64" diameter pile. Additional parameters such component weights in kips are indicated below:

TOPSIDES (Excl. Struct.)	7251 k
RISER TEN.	1554 k
DECK STEEL	3330 k
HULL STEEL	6593 k
HULL MISC.	1123 k
REQ'D BALLAST	1222 k
RESERVE BALLAST	201 k
TENDON TENSION	7600 k
TOTAL	28874k

The main platform components consist of the deck, the substructure (hull and hull appurtenances), risers, the new passive riser tensioner, and the mooring system. Each of these components is discussed in more detail below.

Overall Substructure Arrangement

The TLP substructure is composed of the hull base, the columns, and the tendon support structure or TSS. Figures 2 and 3 show hull general arrangement. The hull is of orthogonally stiffened flat plate construction throughout to facilitate shipyard panel construction. Angle stiffeners are used in lieu of bulb flats due to direct availability of the sizes and material grades required. General overall dimensions and configuration is indicated below:

Draft (ft.)	114
Base Diameter (ft.)	70
Base Height (ft.)	42
Radius to Tendons (ft.)	108
Column Breadth (ft.)	23
Column Width (ft.)	18
Column Height (ft.)	127
Tendon OD (in.)	24
Tendon W.T. (in.)	0.812
Pile OD, (in.)	64
Pile Length (ft.)	320

Base Structure (Figure 4)

The 42-ft. high base structure is octahedral in plan and measures 70 ft. across the flats. The base forms a continuous structure with the tendon support structure to provide continuity and efficient load paths for the tendon loads. Horizontal brackets are used to provide continuous stress flow and to locally stiffen the column connection to the base. The brackets are designed so that there are no weld seams in critical locations. The top plate consists of 5/8-inch plate. The bottom or keel plate has the same structural arrangement as the top plate, except the plate and stiffener dimensions are different. All the plate thickness includes an ABS required corrosion allowance.

The MOSES base is divided into 5 separate tanks consisting of four "wing" tanks and a center tank. Each wing tank is fitted with a swash bulkhead in the center.

Columns (Figure 5)

The columns are 18 ft. wide by 23 ft. long and are subdivided to minimize the effect of flooding. The columns are designed as simple stiffened plate box structures with rounded corners to reduce the drag force on the platform. Watertight flats are located above and below the waterline. The column plating near the waterline (10-ft. above and 8-ft. below) has an additional ¼ inch corrosion allowance (in addition to normal ABS requirements).

Column 1 is designated the "active column" since it houses the only pump room, all other columns are considered passive and normally not manned.

Column 1 has an 8 ft. by 8 ft. access shaft located at the center of the column, which in effect creates a "double skin" to limit any damage from a possible collision. This serves as an access shaft to the pump room below. The one pump room can remotely access all tanks. Two pumps were provided, one electric and one hydraulic.

The upper flat of the other three columns is available for the optional storage of bulk liquids and materials (diesel fuel, potable water and drill water) allowing maximum utilization of topside deck space.

The deck is supported on the top of the hull column by means of 38-inch OD support posts. The lower deck steel is located 8'-0" above the top of column. The 38-inch support posts, four per column, support the deck under the deck girders, which are locally stiffened. The posts are integrated into the top column by extending them six-(6) ft. below the column top and transferring the shear and moment into the hull by means of stiffener brackets.

The top of column bracing structure as shown in Figure 6 maintains the position of the top of columns prior to deck set and also serves as an underdeck catwalk structure during installation and operations.

Tendon Support Structure, TSS (Figure 7)

The 18-ft. wide TSS extends approx. 85 ft. outboard of the columns, provides a continuous structure with the lower column, and contains 2 permanent ballast tanks.

The TSS structure is one of the most critical parts of the hull. This structure has undergone many design reviews and verification checks and a series of FEA analysis. Vertical bracket insert plates are used to stiffen the column-to-TSS connection and to improve stress flow. These bracket structures have been confirmed by detail stress analysis. Weld toe grinding and weld profile detailing are used in this area to get good fatigue performance.

The TSS structure is shaped with a vertical rake toward the TSS extremity. This provides a smooth increase in section modulus of the TSS towards the TSS-to-column juncture and also reduces lateral drag area.

There are several stiffened "box" structures that are internal to the TSS and can be seen in Figure 8. One box runs horizontally and is below the top plate. The lower box is parallel to the bottom TSS rake line. The function of these box structures is to make the TSS rigid to resist the tendon loads. Also, these box structures are designed to take the tendon load and to distribute it into the TSS side shell structure itself. Internal bracketing is used to provide a smooth transition and stress flow from the box beams to the column shell penetrations. In addition, heavy insert side shell plating near the outside ends of the TSS and in way of the internal box structure serve to improve the rigidity of the TSS and improve the stress flow. Heavy plating with superior through thickness properties are used locally at the end of the tendon support beams.

Manway access into the TSS is from the adjacent column. Bolted manways are provided, one on each side of the transverse bulkhead. Similarly, bolted manways are provided between TSS compartments.

All interior spaces are accessible for internal inspection inside these compartments via the horizontal and vertical manway penetrations. These penetrations have been considered for access.

This hull subdivision plan meets all stability and code requirements normally applied to this type of design. The subdivision meets both in-place damage requirements and also satisfies damage requirements for unrestricted offshore tow.

Tendon Porch Receptacles (Figure 9)

The tendon porch receptacles are machined castings welded to the tendon support structure. The tendon porch receptacles are designed for vertical entry of the tendon and are not slotted.

The tendon porch receptacle castings have three stubs that interface with support stiffener plates that are integral with the end of the TSS. The TSS top plate, which is thick at the end of the TSS, is continuous and is flush to the top of the top flange of the tendon porch receptacle casting. The tendon porch receptacle is welded to the TSS top plate and also the three stiffener brackets by continuous complete joint penetration (CJP) welds. These welds are in-situ fully inspectable from both sides. The tendon porch receptacle support brackets are tapered to allow sufficient clearance between the tendon body and the bracket.

Hull Appurtenances

The hull appurtenances are the various permanent structure and equipment located on the outside of the hull. The hull equipment on the inside of the hull is defined as the hull systems. Hull appurtenances are composed of the following:

- SCR and Production Riser supports on base,
- Riser guards,
- Exterior ladders, landings and walkways,
- Padeyes, brackets and miscellaneous structure,
- Tendon porch receptacles,
- Supply boat mooring system, and
- Anode brackets.

Riser Supports

The riser supports for SCRs are shown in Figure 10. These SCR arrangements are similar to the SCR support on TLP pontoons, except they are supported on the side of the MOSES base structure. The slotted receptacle allows the installation of the SCR riser and top head. The SCR support structure on the hull consists of a 2-ft. nominal standoff external "box" structure. The box structure is 5-ft. deep and nominally about 6-½ ft. wide and receives the SCR receptacle weldment. This external structure aligns with the backup hull structure. The future SCR supports consist of bolted receptacle weldments that attach to the permanent support structure.

The top tensioned production riser supports are shown in Figure 11. There are two (2) receptacles located on the West Side and two (2) receptacles located on the East Side. The riser supports consist of 28-inch OD slotted receptacles. These receptacles serve as a guide structure for the risers and as such react the lateral loads imparted by the production risers. No vertical loads are imposed on the riser supports due to the risers, as the passive riser tensioners will be located at deck level. The riser support structure interfaces with the riser keel joint. The slotted receptacle allows the passage of the production riser tieback connector on the outside of the receptacle. The slots are faired and sized to allow unimpeded passage of the 10-3/4 " riser in and out of the slot.

Riser Guards

The riser guard system consists of a supply boat barrier net provided along the side of the platform at the waterline to protect the production risers from boat impact. Two riser guards are required, one on the east and one on the West Side of the platform. The riser guard design utilizes a synthetic rope net, using a 4½" polyester rope, see Figure 12. Supply boat barrier nets will be located such that a supply boat coming from any direction will not impact the production risers. These barriers will be designed to:

1. Absorb the energy of a 217-ft. LOA supply boat, about 3000 s. tons displacement drifting at 1.64 ft/sec, with no contact to the risers.
2. Extend deep enough below the still water height to prevent the stern of the boat from slipping underneath.
3. Extend high enough (including the effects of platform setdown) to prevent the supply boat from climbing over the net.
4. Be highly visible during the day or night.
5. Have a five (5) year service life and be replaceable offshore.

Supply Boat Mooring System

A supply boat mooring system is located on the North side of the platform and consist of two (2) lines attached to the hull columns that attach to the supply boat These lines are located on columns 3 and 4 underneath the crane on platform North. The supply boat operates with a back-down buoy system. A future identical supply boat mooring system will be installed at the south side of the platform on columns 1 and 2. Padeyes are installed in the shipyard on the columns 1 and 2 to facilitate the future installation of the mooring lines offshore. The boat mooring will be designed for a 217 to 228-ft. length overall (LOA) boat with a draft of 14 to 16 ft., beam of 42 to 44 ft., and displacement of about 3000 s. tons. For design, maximum operating conditions with the boat moored will be 6 to 10 ft. significant wave height (Hs), 30-knot wind and 1-knot surface current. The moorings will be designed to allow the boat to either point its bow into the seas to shelter the aft deck from waves, or to stand off the platform leeside with its stern into the waves. The moorings are rugged enough to survive a 100-year design hurricane with no boat attached.

Mooring System (Figure 13, 14, 15)

The mooring system consist of eight (8) tethers that connect the hull to the foundation piling and consists of the following components:

1. Foundation Piles
2. Tendon Assemblies composed of a Top Segment, 4 Main Body Segments, and Bottom Segment.
3. Top and Bottom Connectors and Couplings
4. Tendon Porch Weldments
5. Anodes and carrier frames
6. Tendon support buoys for installation only
7. Tendon Tension monitoring devices

Two tendons extend from the tendon porches at the end of each TSS section of the hull to the tendon receptacles mounted in the top of the foundation piles. Each tendon consists of a 24-inch diameter, 0.812-inch wall thickness tubular, a top connector assembly, and a bottom connector assembly. The length of each tendon varies to accommodate the sea bottom slope, but is approximately 1428 ft. long. Three spare main body sections were fabricated in case of damage to the primary sections.

Due to the critical nature of the tendon bodies they were supplied with a special thermo-mechanically controlled process steel, TMCP, with a yield strength of 70 ksi. Tendon bodies were supplied with a polyethylene outer coating by Sumitomo Corporation. Fabrication of the tendon bodies and tendon porch assembly was completed in nine (9) months by Gulf Marine fabricators. All connectors including main body couplings and top and bottom connectors complete with flexbearing were supplied by Oil States Industries.

Tendon Top Connector Assembly, TTCA

The TTCA is composed of two major assemblies, the Top Connector Assembly, TCA, and the Length Adjustment Joint, LAJ. The TCA consists of a set of hydraulically actuated slips and is securely mounted in the tendon porch prior to departure from the onshore location. This arrangement provides adequate protection to the assembly until the installation process begins. The control panel for activation of the TCA was securely fastened to a temporary installation platform during transport. The hydraulic lines connecting the panel to the TCAs was pre-routed and secured to the hull and legs.

Each LAJ was welded to the top tendon section along with the Load Monitoring Unit, LMU, at the onshore site and stored in a purpose built cradle for transport offshore. The LAJ allowed each tendon to have approximately 8 feet of adjustment for water depth and top of pile elevation differences.

Tendon Bottom Connector Assembly, TBCA

The TBCA consists of two distinct elements, the FEC and receptacle. The receptacle is a large steel cylinder with no moving parts. The receptacle is welded to the foundation pile during fabrication with a drive head welded to the top of the receptacle to provide strength during driving of the foundation pile.

The FEC houses the FlexJoint and mates with the receptacle to secure the tendon to the seabed. The FEC was welded to a segment of the tendon during onshore fabrication. The FEC and Tendon unit were secured in a horizontal position in a purpose built cradle that securely supported the FEC's tendon extension and nose of the FEC in a manner that would prevent flexure of the FlexJoint during transport.

Merlin Tendon Coupling

The Merlin Coupling was welded to the tendon segments at the onshore fabrication yard. The potential for damage during handling and transport is generally during loading or offloading of the transport vessel and careful handling of the Merlin equipped tendon segments using purpose built handling tools minimized any damage. During transport the tendon segments were securely fastened to the vessel's deck to prevent movement and impact damage. All Merlin couplings were shielded from impacts using "protectors" installed on the pin and box couplings.

Riser

Wells will be tied back from the seafloor to the surface platform with single casing production risers providing direct vertical access, dry trees. The well configuration will include a 3-1/2 inch 9.3 ppf tubing for oil and a 1.9 in 2.9 ppf tubing for gas inside the 10-3/4 inch casing. Completion design will include a tubing hanger approximately 200 ft. below the mudline, which will support the downhole tubing. Tubing above this hanger and in the riser must be supported by the platform. The shut-in tubing pressure at the surface will be approximately 8800 psig. The surface wellheads and trees are be rated for 10,000-psig pressure. Well completions were perforated and gravel packed.

There are four top tensioned production risers on Prince TLP, one at each of four columns. The riser system components were supplied by FMC, see Figures 16 and 17. The production riser outer casing is 10-3/4 inch, 81.0 lb/ft, L-80 grade pipe utilizing all high fatigue connectors. The connectors, designed and supplied by Oil Patch Technologies were subjected to FEA, ISO testing, and fatigue testing. This included full-scale testing with respect to functionality including make-up/break-out. The base of the riser includes a tapered stress joint and an external wellhead coupling. Components of the riser system include:

1. 18 ¾" Torus 4 Tieback Connector, 10,000psi
2. 10 ¾" Stress Joint 95 ksi yield steel , 35 ft. long
3. 10 ¾" O.D. Production Riser Joints, 40 ft. long
4. ZF-2000 pin and box threaded connectors with metal to metal seals
5. 10 ¾" OD Production Riser Tensioner Joint, 0.747 wall x 20 ft. long, A707 grade 80 ksi
6. Production Riser Tensioning System

Passive Riser Tensioner

Each production riser is dynamically supported by a tensioner assembly. The tensioner assembly allows relative motions between the riser and surface facility. The Prince Tensioner is a passive spring tensioner, see Figure 18, with the following characteristics:

- Stroke is approximately 48 inches (12 inches upstroke and 36" downstroke).
- 175,000 lbs. preload
- 150,000 lbs. spring stiffness
- 6 degree max riser deflection
- 5,330lbs/deg rotational stiffness
- Visual Tension Indication
- Dimensions 68" OD x 70" high
- Split assembly for ease of riser installation

This tensioner has the benefit of much lower cost and reduced maintenance requirements.

Strakes

The VIV assessment indicated that 300 ft. of strakes were required and that it was advantageous to have strakes on one joint above the keel joint and seven joints below the keel joint, since the current was greater near the surface. Strakes were molded marine grade polyurethane, Pitch 5D, with a strake height of 0.13D.

Keel joint

A unique keel joint in the riser is supported by the receptacles discussed under the riser supports above. Thus the TLP hull base restrains the riser keel joint and bushing laterally. The keel joint is composed of an inner pipe tapered section, A707 grade 80 ksi, 40 ft. long, and an outer pipe 24" OD, 52 ksi steel, 20 ft. long, see Figure 19. A bushing split in 2 halves is pre-attached to keel guide to transfer loads to the outer pipe and through to the hull receptacle. The lateral restraint of the riser at this point reduces the stroke required of the tensioner.

Milestone Schedule Points

Discovery Well	July 1994
Delineation Wells	October1998
Royalty Relief based on SPAR	June 1997
Royalty Relief Based on TLP	April1999
Bid SPAR/TLP Options	April-June 1999
Award Sunday Silence TLP Contract	July 1999
Award Deck Contract to Omega	May 2000
Commence Fabrication of Hull	Sept 1999
Temporary Suspension of Construction	Sept 1999
Study Subsea tie-back	Sept 1999/March 2000
Award Prince TLP Contract	March 2000
Commence Hull Fabrication	April 2000
Complete Hull Fabrication	June 2001
Piling Installation	May 2000
Tendon Installation	June 2001
Hull and Deck Installation	July 2001
First Oil	Sept 2001

TLP Design and Analysis

The Prince TLP design followed the standard industry practice and applicable ABS and USCG rules and API recommendations. State-of-the-art analyses were carried out using a combination of commercial software and in-house developed interface software and spreadsheets.

TLP Sizing

The Prince TLP sizing was carried out using in-house developed spreadsheet. This sophisticated sizing spreadsheet estimates production riser and SCR pretension requirements, deck structure weight and hull structure weight. It also estimates dynamic tendon tension based on a simplified analytical model. It performs a preliminary tendon strength and collapse utilization check. It calculates minimum air-gap and minimum tendon tension for a number of design conditions. Based on topside facility weight, it enables one to optimize the TLP configuration by varying the hull principle dimensions and tendon configuration. This spreadsheet has been proven to be a useful design tool and its results are typically within a few percentages of those predicted by global performance analysis.

Global Performance Analysis

Global performance analysis was carried out in the frequency domain using MIT's diffraction analysis program WAMIT and in-house developed spreadsheet. WAMIT computes the TLP motion RAOs that are imported into the global performance spreadsheet. This spreadsheet calculates the TLP offset, set-down, air-gap, motion, acceleration and tendon tension, according to calibration coefficients derived from model tests. The efficiency of this approach enables one to evaluate a large number of load cases in relative short amount of time.

In addition to the above frequency domain approach, fully coupled time domain analysis was carried out using the Texas A&M's program Winpost. In this approach, the TLP is treated as a special mass element that receives first order and second order hydrodynamic coefficients from WAMIT. The tendons and risers are modeled as structure beam elements capable of large displacement. Comparison with experimental results indicates that Winpost not only predicts the first order response quantities accurately but also predicts the second order quantities such as high frequency tendon tension with reasonable accuracy. It predicts accurately the dynamic tendon tension difference between up-wave tendons and down-wave tendons.

Response based analysis was also performed in order to gain more confidence in the maximum and minimum tendon tension. The results showed that our approach based on extreme design environment is conservative.

Model Tests

Wave basin model tests were carried out at OTRC in April 1999. The tests included 50 year, 100 year and 1000 year Hurricane sea-states. Each sea-state had a minimum of two random wave realizations. Regular wave test, white noise test and fatigue sea-state test were also performed.

Comparison of model test results and global performance analysis results indicated good agreement between predicted and measured maximum and minimum tendon tension, platform motion and acceleration, as well as air-gap. The model tests confirmed the analytical results and no configuration adjustment was necessary.

The model test results affirmed the advantages of MOSES TLP design. Because of its deeply submerged base and small columns, the MOSES TLP has low horizontal platform acceleration, small high frequency tendon tension response and small wave enhancement. The horizontal platform acceleration is about 0.2g. The standard deviation of high frequency tendon tension response is less than 0.25 times that of wave frequency response. Enhanced wave crest is only 1.25 times the significant wave height Hs. These advantages coupled with the ability to adjust tendon spacing enable one to arrive at an efficient TLP design.

The model test data were post-processed and further calibration coefficients were developed for platform motion, acceleration, tendon tension and wave enhancement. The calibration coefficients were incorporated in the global performance analysis.

Tendon Analysis

Tendon analysis was performed using MCS' computer program Flexcom3D. Motion RAOs were developed in WAMIT as input to Flexcom3D. Time domain simulations were performed for both extreme and fatigue sea-states. The results were post-processed and tendon utilization and fatigue life were derived.

Extensive tendon installation analysis was performed with the buoyancy cans to insure tendon integrity. Resultant fatigue damage was added to the total tendon fatigue damage.

Tendon VIV analysis was performed and it was determined that no strake was needed for the tendon. Resultant fatigue damage to the tendon was added to the total tendon fatigue damage.

Fracture mechanics analysis was also performed to determine the maximum allowable initial crack size.

Hull Structure Design and Analysis

Extensive finite element analyses (FEA) were performed for the Prince TLP using the computer program ANSYS.

A global structure model was developed to evaluate the global structure behavior of the TLP and provide cut-boundary loads for further local structure FEA. Design waves were developed based on such dominant load parameters as maximum tendon tension, maximum deck acceleration and maximum squeeze-pry load. The global structure model was mass calibrated to produce the correct inertia load response. Pressure and acceleration were mapped from the WAMIT hydrodynamic model to the ANSYS structure model. Using in-house developed data management tool, the control element groups and load cases were identified for further local structure analyses. Principle stresses were extracted to perform bulking check of the structure using DnV 30.1 rules.

The global structure model was also used to perform global fatigue analysis of the TLP structure. Using the pressure and acceleration mapped from WAMIT diffraction analysis for a number of wave frequencies, a frequency domain fatigue analysis was performed and fatigue life was calculated for structure elements in a number of control element groups. Weibull peak parameters were derived such that in local fatigue analysis, stress in 100-year extreme sea-state can be used to determine the fatigue life. Fatigue analysis results indicated that the Prince TLP behaves exceptionally well in terms of fatigue.

Using the cut-boundary loads from the global structure model, local fine mesh structure models were built for topsides to column connection, tendon porch area, TSS and column connection, bulkheads, flats, ring girders and etc. The structure is re-designed locally if necessary to ensure that neither stress nor fatigue damage exceeds the design allowable.

Weight Management and Monitoring

Floating structures like TLP requires extensive weight management and monitoring. The Prince TLP was that much so because the project was based on lump-sum and was competitively bid. The challenge was met by paying earlier and detailed attention to the weight management aspects of the project.

A detailed weight take-off was developed in the earlier design stage and weight budget for each discipline was developed. Independent weight take-off was conducted to ensure weight accuracy. During TLP hull fabrication, each construction module was weighed and the weighed weight was compared carefully with calculated weight.

In the final weighing of the hull, the calculated weight was well within 0.5% of the weighed weight. The weighed weight was below the budget weight by more than 100 kips and resulted in increased ballast reserve.

Fabrication

Tendons

As with most other TLPs, Sumitomo supplied the 24" diameter tendon body pipe. In total 220 pipe joints of approximately 56 ft. 11 in. length, with 1/8 inch thick side extruded polyethylene coating applied to within 12 to 14 inches of each end, were welded into three segments for each tendon — 284 ft. long main bodies, 112 ft. long top segment, and 180 ft. bottom segment. Gulf Marine Fabricators in Corpus Christi, Texas fabricated the tendons. A total 43 tendon couplings sets (pin and box) were provided for welding on to the end of each segment. Figure 21.

Hull

The hull is mostly orthogonal stiffened flat plate. This allows use of the shipyard panel line facility and significantly reduces cost and fabrication time. The Prince TLP hull, 3300 short tons, was fabricated by AMFELS at their Brownsville shipyard and took approximately 15 months. The hull was constructed into stiffened flat plate segments composed of angles and plate up to ¾ inch using modified 2MT1 and 2Y steel. The flat plate segments were then fabricated into blocks of 100 to 300 tons that were transported via heavy block carriers and assembled into the final hull form at quayside location. The final completed hull was skidded from the quay onto a floating dry dock where final testing was conducted. See Figure 22.

Installation – Figure 23

A very detailed account of the fabrication and installation of the Prince TLP is presented in OTC Paper No. 14178 "Construction and Installation of the Prince TLP". The installation of the entire TLP unit, hull, mooring and deck was executed by Heerema Marine Contractors, under subcontract to MODEC.

Project Cost Summary

The total cost of the Prince platform including hull, mooring, and topsides, is approximately $120 MM. The export pipelines costs were approximately $24 MM.

Lessons Learned

The "Lessons Learned" that follow were developed from a broad range of personnel – business development, project, and operations:

1. Concept selection should be a planned well-documented process involving a wide range of decision-makers. Documentation of the results for the various concepts should include cost, schedules, advantages and disadvantages of each concept as well as the basis of the final decision.
2. Second guessing the concept selection decision late in the project execution phase is expensive, generally results in delays to first oil, and ultimately devalues the NPV.
3. The process of granting Royalty Relief is not formally set-up for revision but did show considerable flexibility to accommodate a change in the field development concept.
4. Competitively bidding different deepwater concepts allows determination of the lowest price concept under market conditions, but is expensive for contractors. This process is very costly for unsuccessful contractors as it involves the execution of considerable amount of design work prior to contract award. These cost are never recovered.
5. Meeting USCG rules and regulations, including, NAVICS, for each project component is essential for getting approval to produce.
6. The ballast system on Prince was classified as a Passive system by USCG unlike those of semi-submersibles. Classification depended upon how often ballast was moved. Ballast is moved on Prince only for significant rig moves.
7. Get Operations input early in design phase.
8. Leased rigs are now available with dynamic capability and overall project economics favor leasing over purpose built dedicated rig for the life of the field. Cost of rig ownership is high due to maintenance.
9. Tendon strakes may be needed where current profiles are

significant. No strakes were required on Prince but current profiles for platforms further south and east may be significantly more extreme and may extend to deeper depths than expected.

10. An elevator to the TLP pump room may be preferred by production personnel, but economics and frequency of use must be considered.
11. Forced Ventilation and Dehumidification for bulk storage areas in hull are recommended.
12. Equipment porches to be more accessible to cranes; if supplied with 2 cranes, access porches for both cranes are needed.
13. Both cranes should be supplied by the same vendor (part stocking and interchanging).
14. Permanent 480 volt disconnect on the top deck is needed to supply power to temporary buildings.
15. The Installation windows for Prince and Brutus overlapped and took considerable discussions among several parties to reach consensus on which project was installed first.

Reference

1. Gore, C.T. and Mekha, Basim B.: "Common Sense Requirements CSRs) for Steel Catenary Risers (SCRs)", paper OTC 14153 presented at the 2002 Offshore Technology Conference and Exhibition, Houston, May 6 – 9.

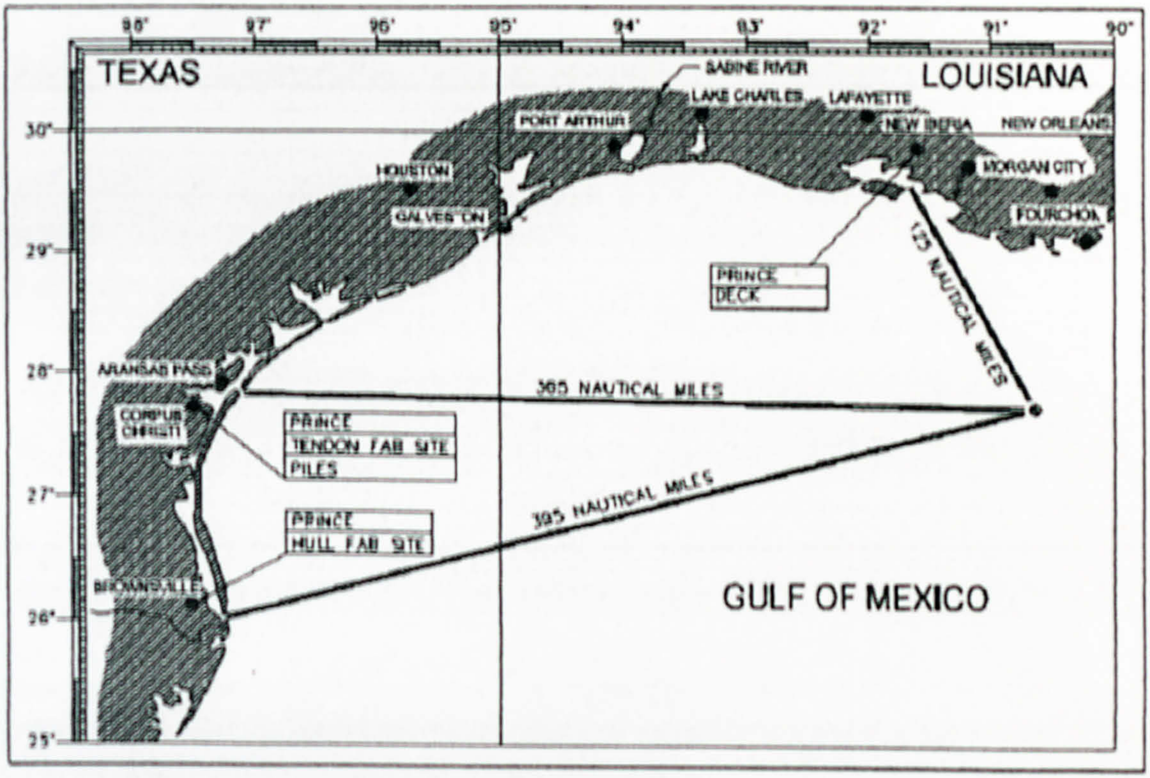

Figure 1: Location Map – Prince Project